Some ^

Non-Accelerator Neutrino Physics*

Jeanne Wilson

IoP HEPP 2013, Liverpool

8/4/2013

*Excluding neutrino mass measurements

Content

- Probing neutrino properties
  - Reactor neutrinos: θ_{13}, $\Delta m_{12,}$ reactor anomaly
  - Low energy solar neutrinos: LMA, MSW, new physics
  - Mass hierarchy
- Probing neutrino sources
  - SuperNova physics
  - Geo Neutrinos
  - Solar Physics
    - Core metallicity
    - Luminosity constraint

Experiments

- SNO+ (780t LS)
- Borexino(280t LS), KamLAND (1kt LS)
- Daya Bay, RENO, Double Chooz (Gd-LS)
- Proposed experiments:
  - LAGUNA:
    - Memphis (100kt H_2O Cerenkov)
    - Glacier (100kt liquid Ar)
    - LENA (5kt LS)
  - HyperKamiokande (H_2O Cerenkov)
  - Daya Bay II (20kt LS)
- SuperK (H_2O Cerenkov), IceCube/DeepCore/PINGU (Ice Cerenkov), KM3NeT(sea Cerenkov), Anita (Balloon radio), Askaryan Radio Array* (*Track 4 talk by J Davies)

LS Detector: SNO+

$\nu_{e,x} + e^- \rightarrow \nu_{e,x} + e^-$

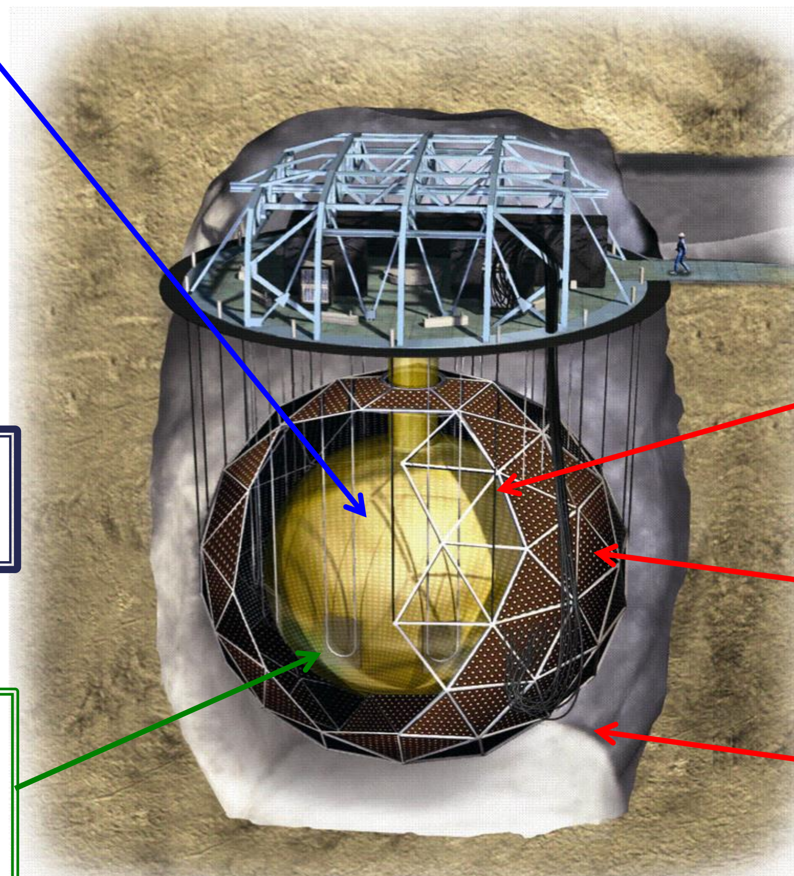
$\bar{\nu}_e + p \rightarrow n + e^+$

780 tonnes linear alkyl benzene (LAB) liquid scintillator
Low energy threshold for solar measurements

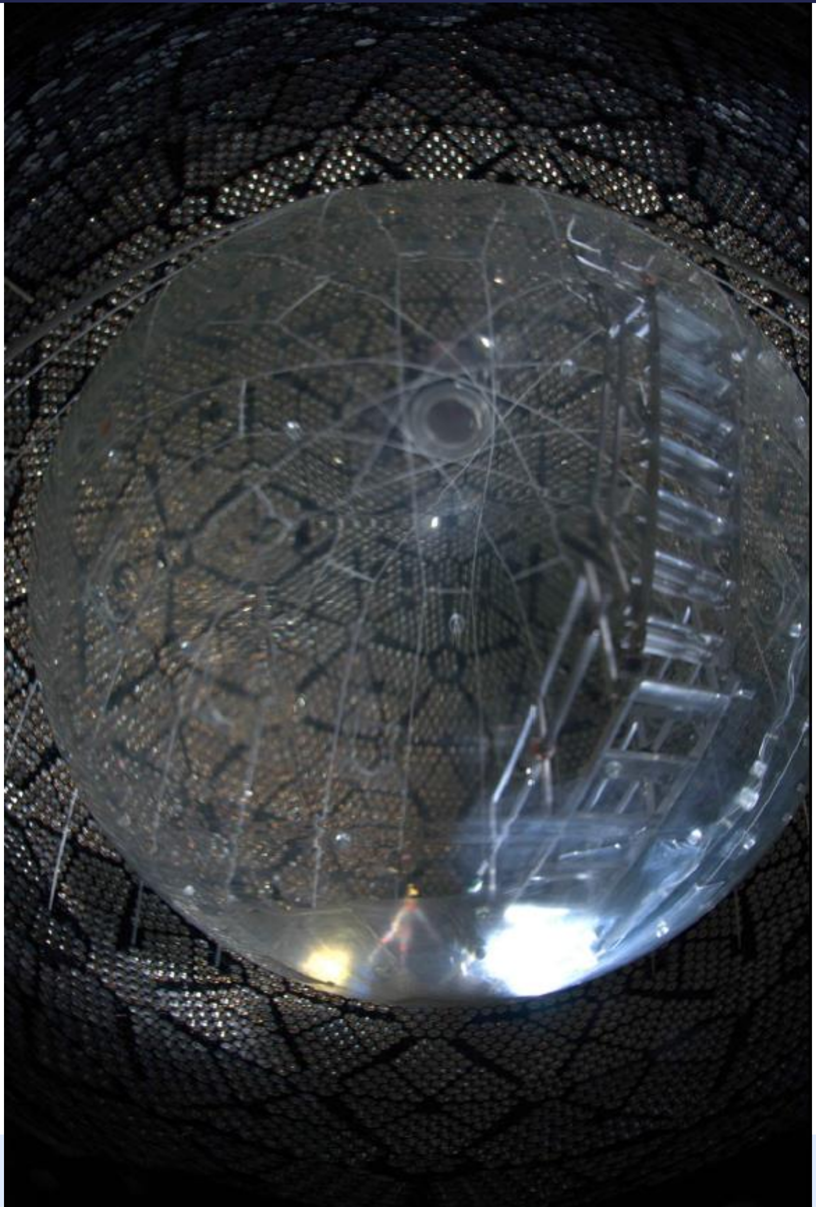
2km underground, 6000 mwe
Ultra-low CR μ background
No ^{11}C

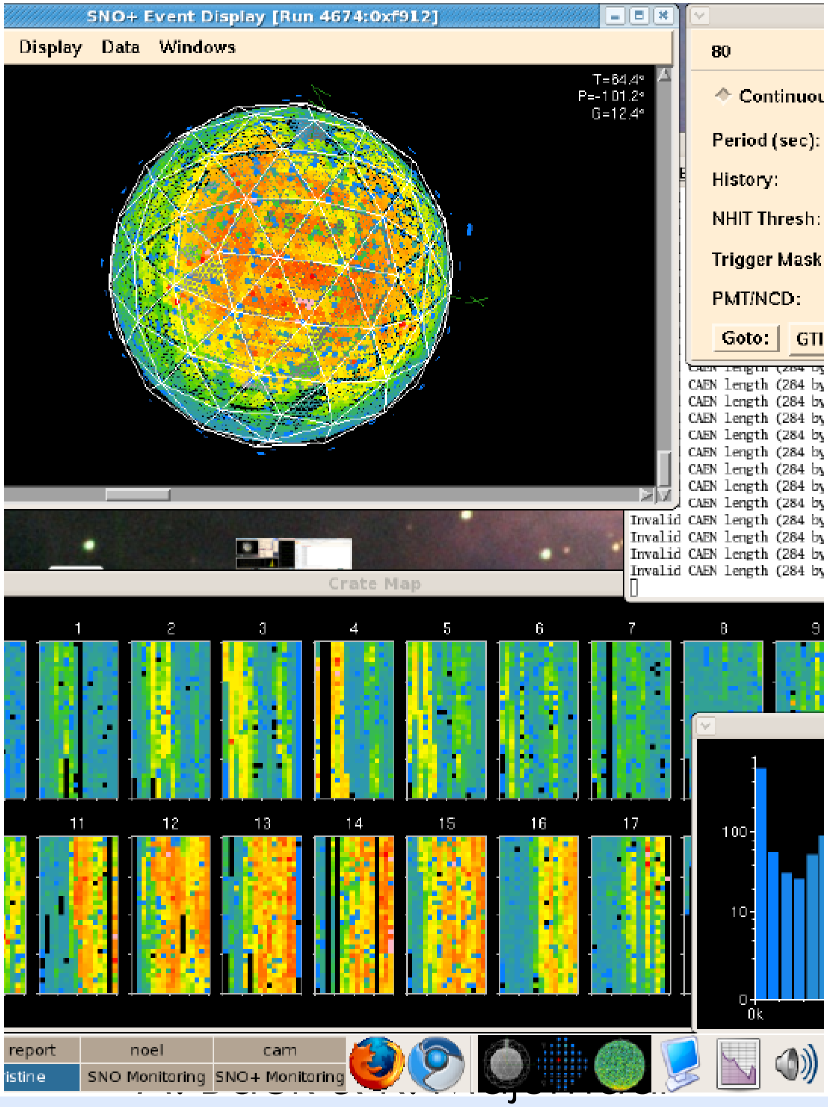
Very low backgrounds
U, Th < 10^{-17} g/g

Separate phase: Isotope loading for 0νββ measurement

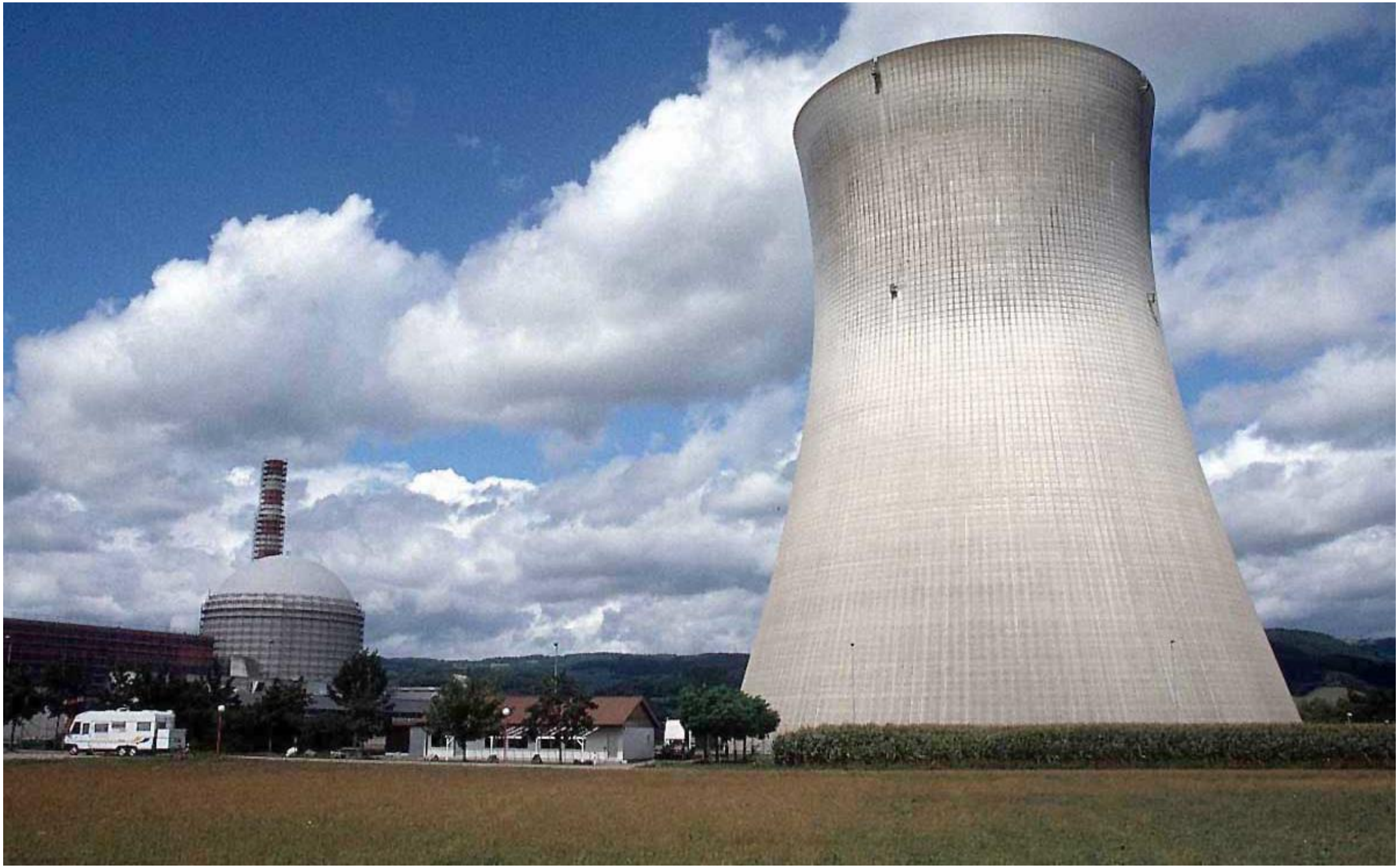


SNO+ status




SNO+ Event Display [Run 4674:0xf912]
Display
Data
Windows
T=64.4°
P=-101.2°
G=12.4°
80
Continuou
Period (sec):
History:
NHIT Thresh:
Trigger Mask
PMT/NCD:
Goto:
Crate Map
report
noel
cam
SNO Monitoring
SNO+ Monitoring

Reactor Neutrinos



Reactor neutrinos

$\bar{\nu}_e + p \rightarrow n + e^+$

$\bar{\nu}_1$-$\bar{\nu}_3$
Daya Bay
RENO
Double Chooz

$\bar{\nu}_1$-$\bar{\nu}_2$
Non-vacuum

KamLAND
SNO+

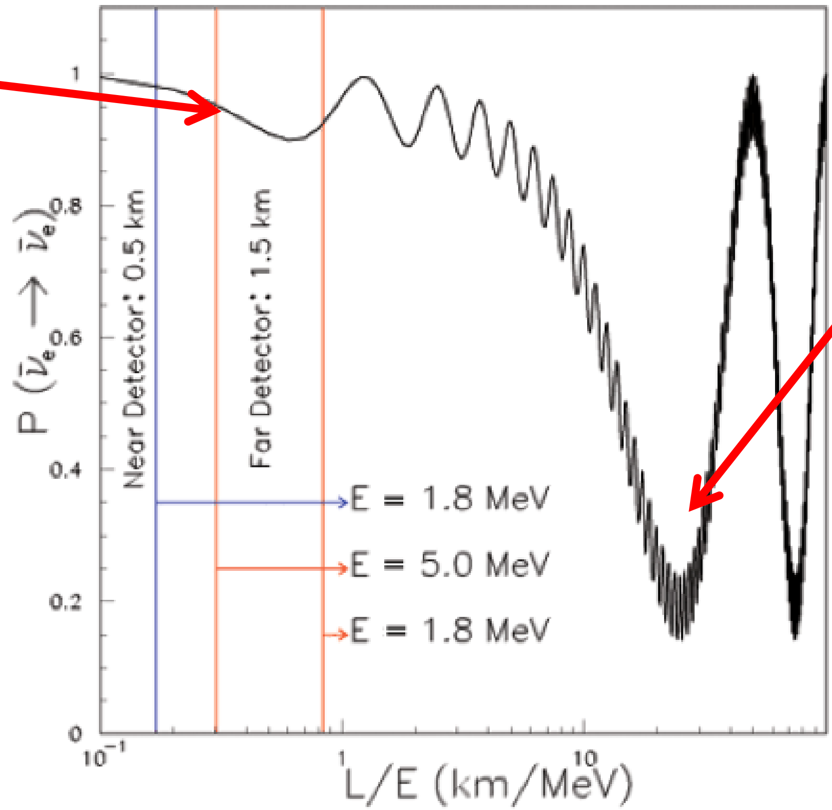


FIG. 3: Antineutrino survival probability $P(\bar{\nu}_e \rightarrow \bar{\nu}_e)$ as function of the ratio L/E [km/MeV]. Vertical lines indicate some relevant reactor neutrino energies. $E = 1.8$ MeV corresponds to the reaction threshold. The peak of the energy spectrum weighted by the detection cross section in the absence of oscillation is at $E \sim 4$ MeV, and the contribution of neutrinos with energy $\lesssim 5$ MeV is the most important.

TOP TRUMPS®

COLLECTABLE, COMPETITIVE, COMPULSIVE!

Daya Bay θ_{13}

Reactor power: 6×2.9GW

Far Detectors: 1

Near Detectors: 2

Analysis type: rate

$\Theta_{13}>0$ significance: 7.7σ

RENO ν θ_{13}

Reactor power: 6×2.8GW

Far Detectors: 1

Near Detectors: 1

Analysis type: rate

$\Theta_{13}>0$ significance: 4.9σ

DOUBLE Chooz

Reactor power: 2×4.25GW

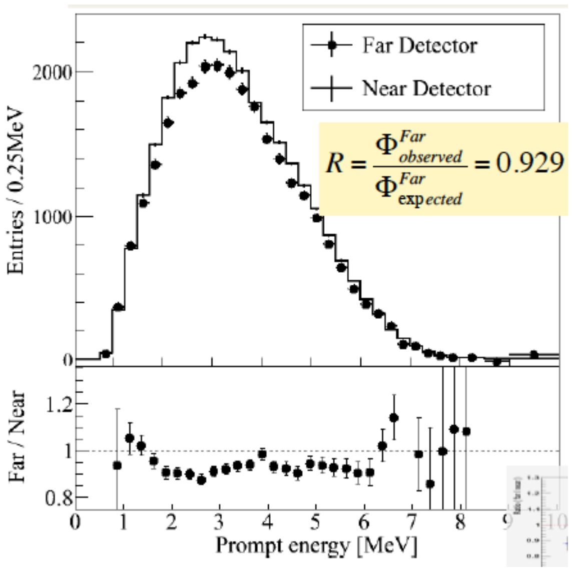
Far Detectors: 1

Near Detectors: 0 (1)

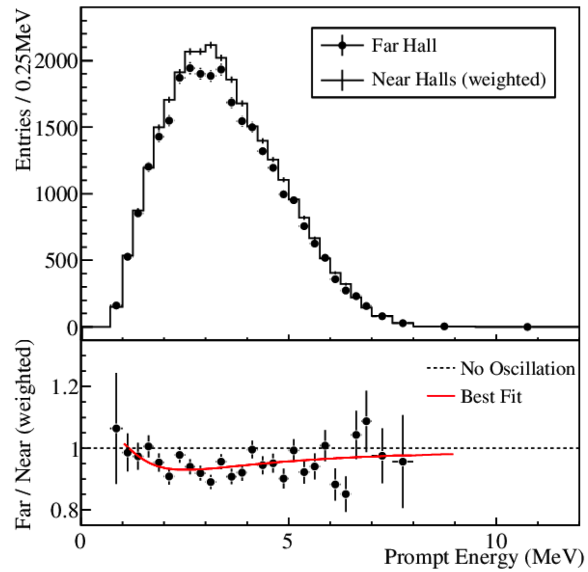
Analysis: rate+spectrum

$\Theta_{13}>0$ significance: 2.9σ

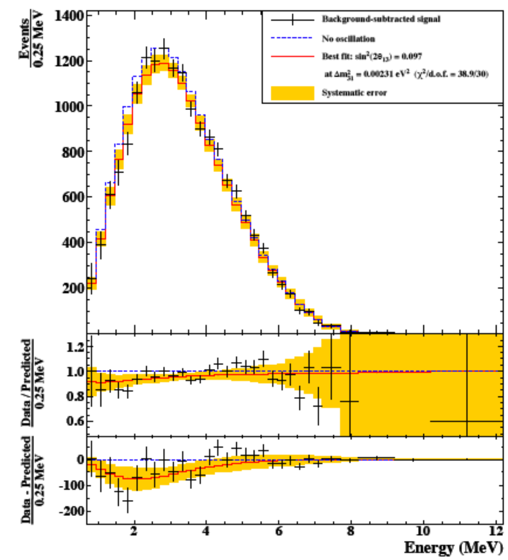
Daya Bay, RENO, Double Chooz



RENO



Daya Bay



Double Chooz

Experiment	$\sin^2 2\theta_{13}$	*stat.*	*syst.*
RENO	0.100	± 0.010	± 0.015
Daya Bay	0.089	± 0.010	± 0.005
Dbl Chooz H	0.097	± 0.034	± 0.034
Dbl Chooz Gd	0.109	± 0.030	± 0.025

Rate only (RENO, Daya Bay)

Rate + Shape (Dbl Chooz H, Dbl Chooz Gd)

TOP TRUMPS®

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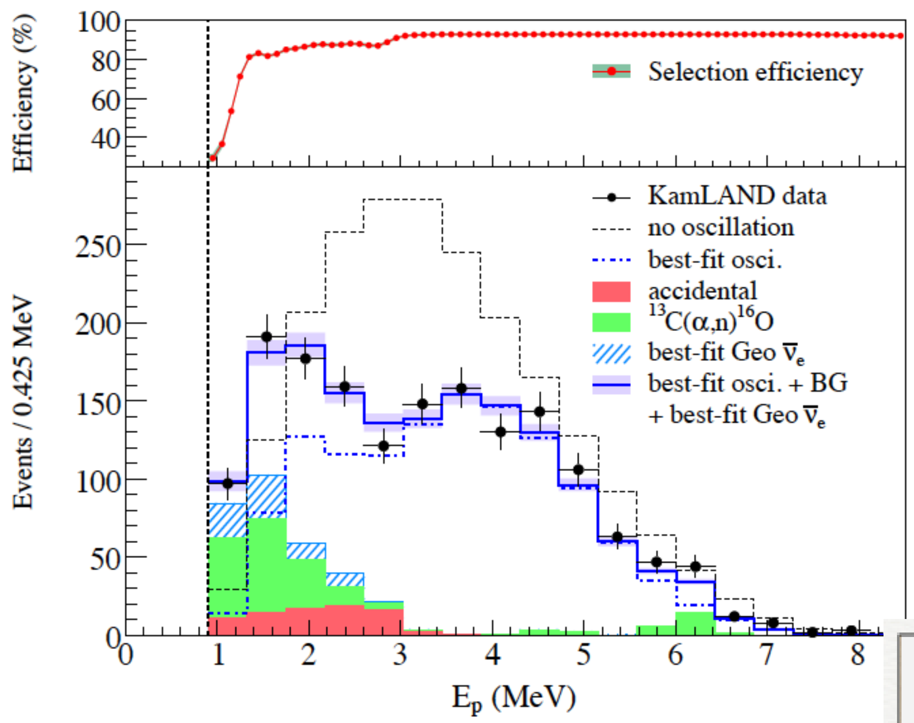
KamLAND

- Size: 1kton
- nPMTs: 2100
- Depth: 2700m.w.e.
- E resolution: 7.5%/√E
- 1st data: March 2002

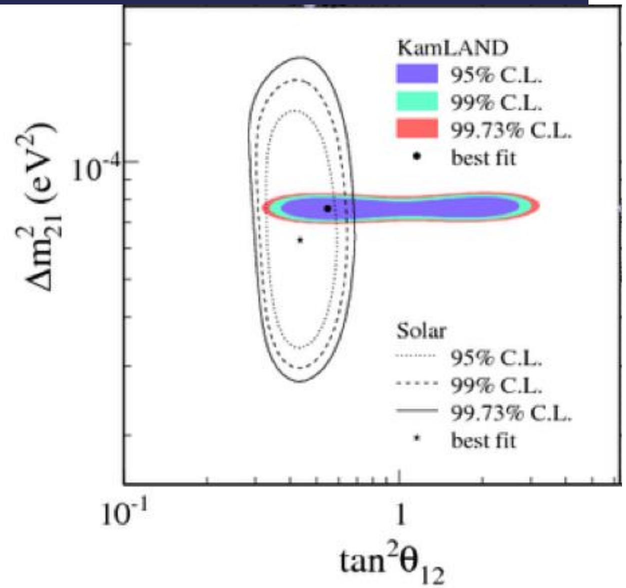
SNO+

- Size: 780 ton
- nPMTs: ~9500
- Depth: 6000 m.w.e.
- E resolution: 5%/√E
- 1st data: 2014

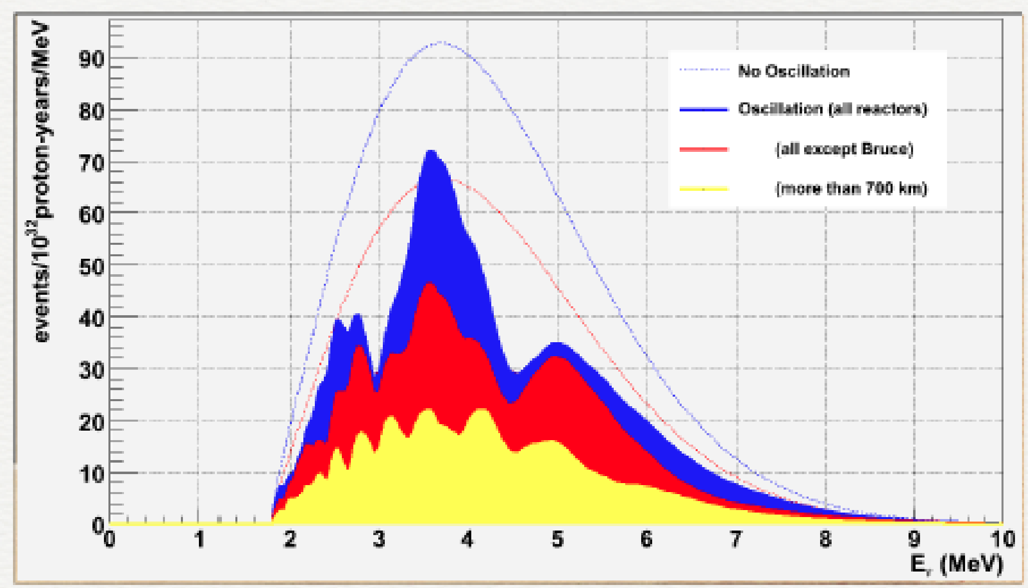
Reactors – Δm^2_{12} (Θ_{12})



KamLAND
Phys. Rev. Lett
100, 221803
(2008)
arXiv:0801.458



Non vacuum oscillations
SNO+ should see clear dip



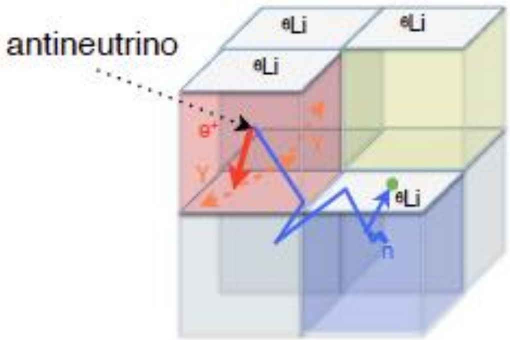
Reactor Anomaly

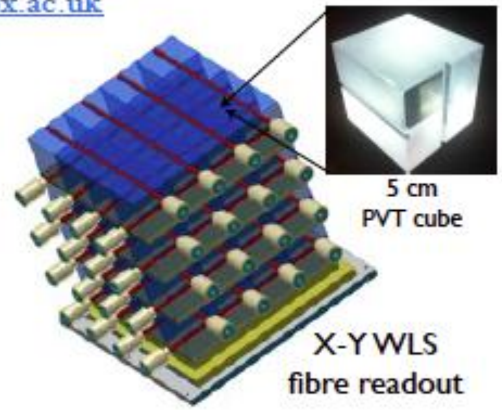
- Experiments at <100m from reactors measure $\bar{\nu}$ fluxes ~0.94×prediction (deviates from 1 @ 98.6% C.L.)
- Fourth non-standard ν state driving oscillations at short distances?

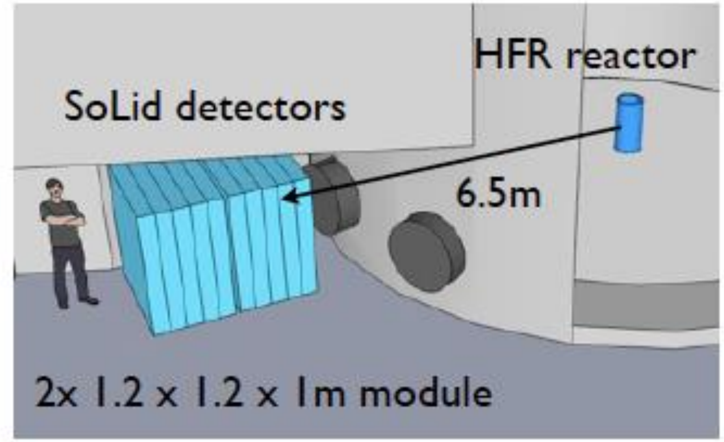
Phys.Rev.D83:073006,2011

SoLid at ILL

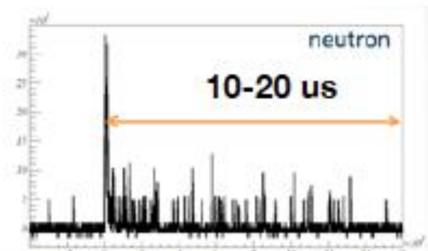
http://www2.physics.ox.ac.uk/research/mars-project/solid
contact : antonin.vacheret@physics.ox.ac.uk

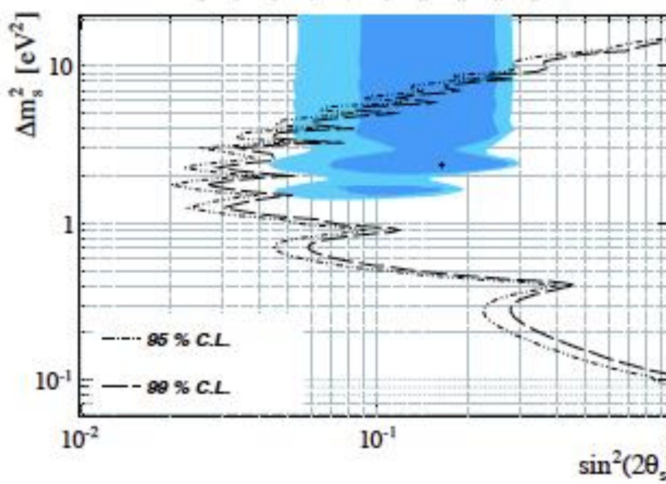






- ILL-HFR 58 MW compact reactor core and very short baseline (from 6m) provides high sensitivity to search for short oscillations
- Novel detector technology based on composite plastic/ 6LiF:ZnS(Ag) scintillators
  - high neutron-gamma discrimination (~10^{-7}) enables trigger on neutron signal
  - Digitiser electronics and compact read out system (MPPC)
  - Good energy resolution (0.2 @ 1 MeV)
- highly segmented volume and 3D reconstruction
  - unprecedented background rejection capability !
- limited gamma shielding needed and active muon veto
- 2x 1.44T Fiducial (11k cubes, 2k chans) & 2 years running (300days/year) from early 2015
- prototype in construction & proposal in preparation



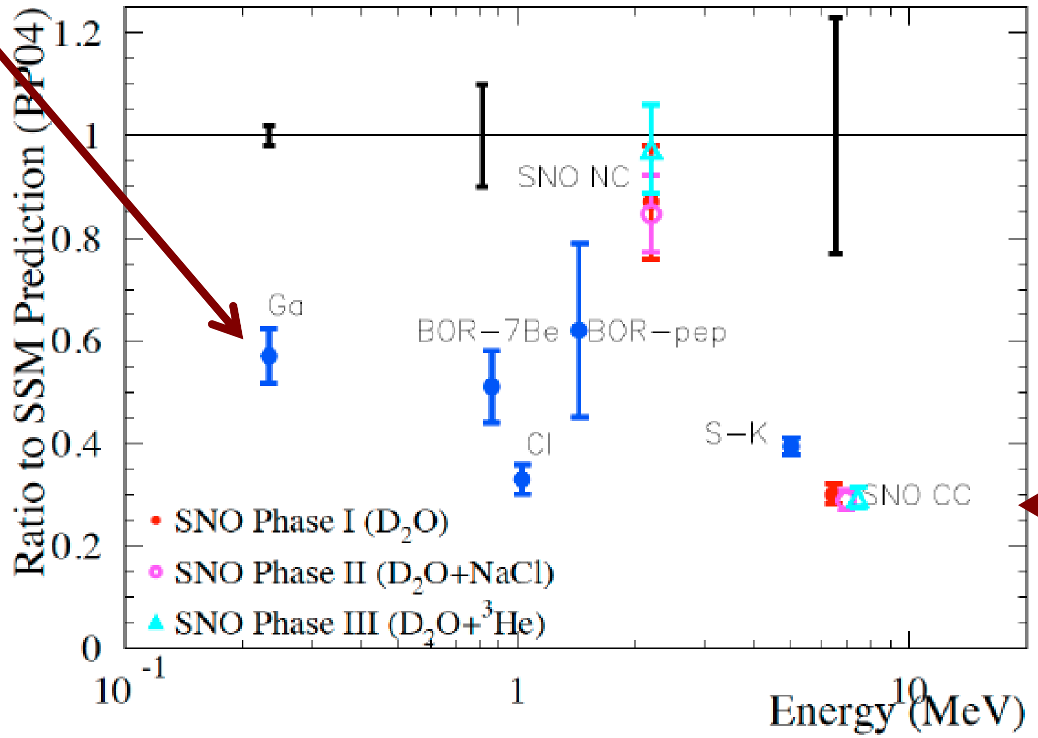


Solar Neutrino Physics

Solar Neutrino Oscillations - status

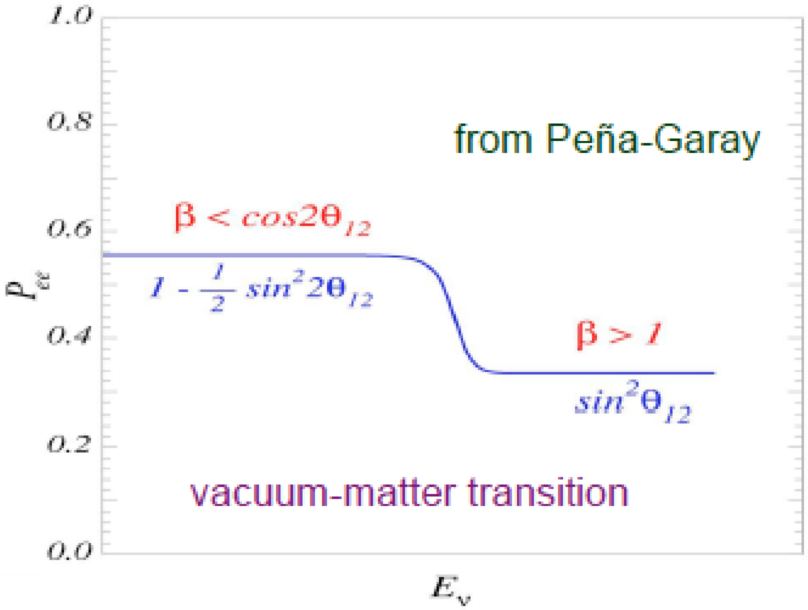
Mixing parameters: (LMA)
$\Delta m^2_{12} = 7.59 \pm 0.21 \times 10^{-5}$ eV^2
$\vartheta_{12} = 34° \pm 1°$

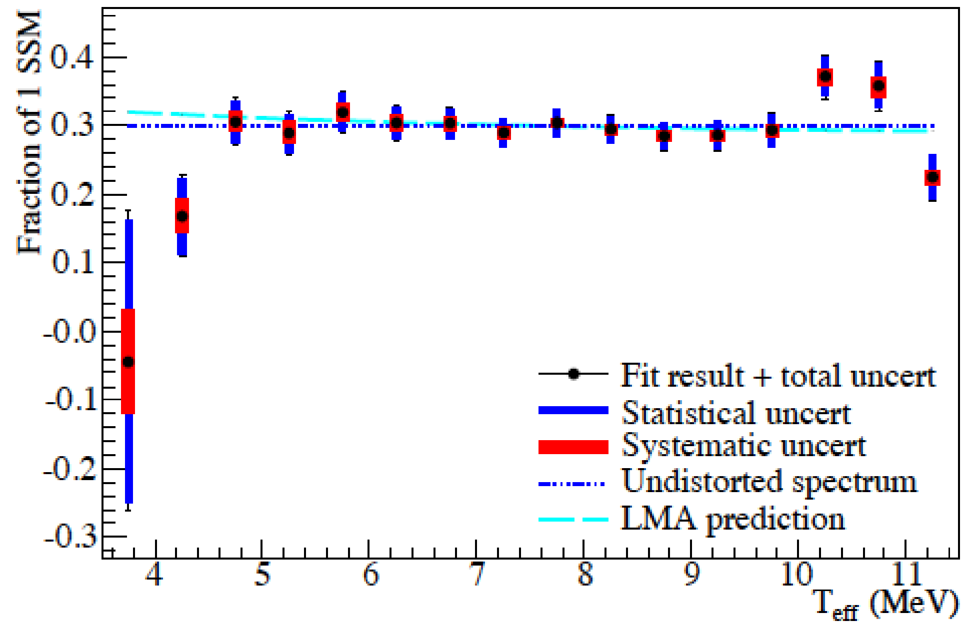
Vacuum oscillations



MSW

Solar Neutrino Oscillations - status



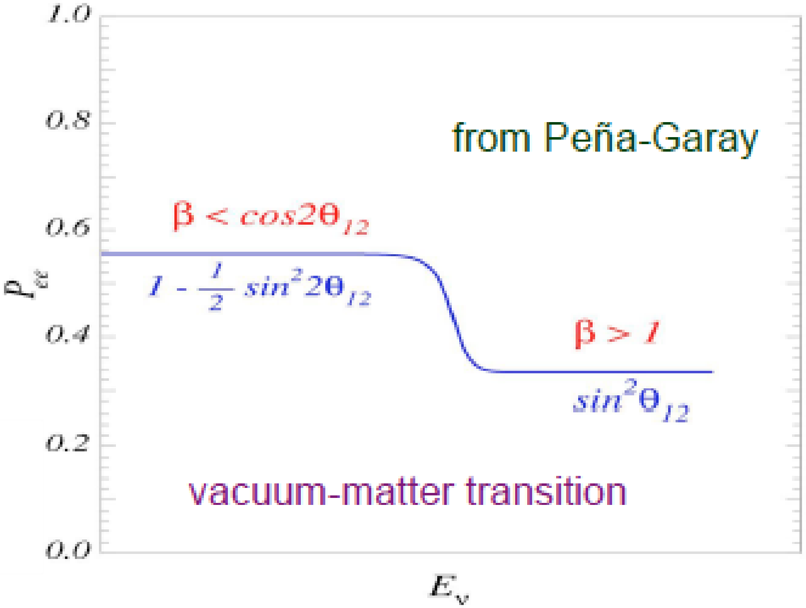


Δm^2_{12} and θ_{12} suggest MSW but direct evidence would be nice

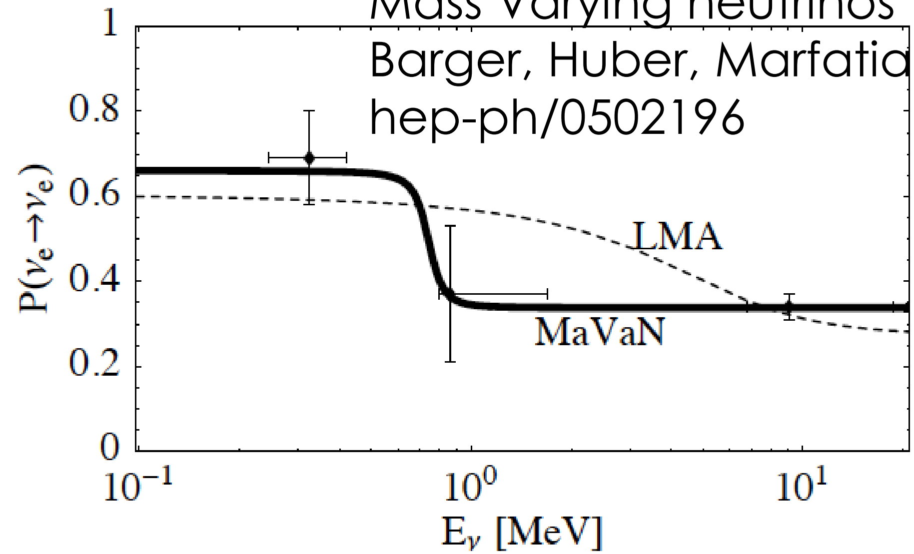
- Day-Night asymmetry
- Spectral distortion of ^{8}B vs

SNO: http://arxiv.org/abs/0910.2984

Solar Neutrino Oscillations - status

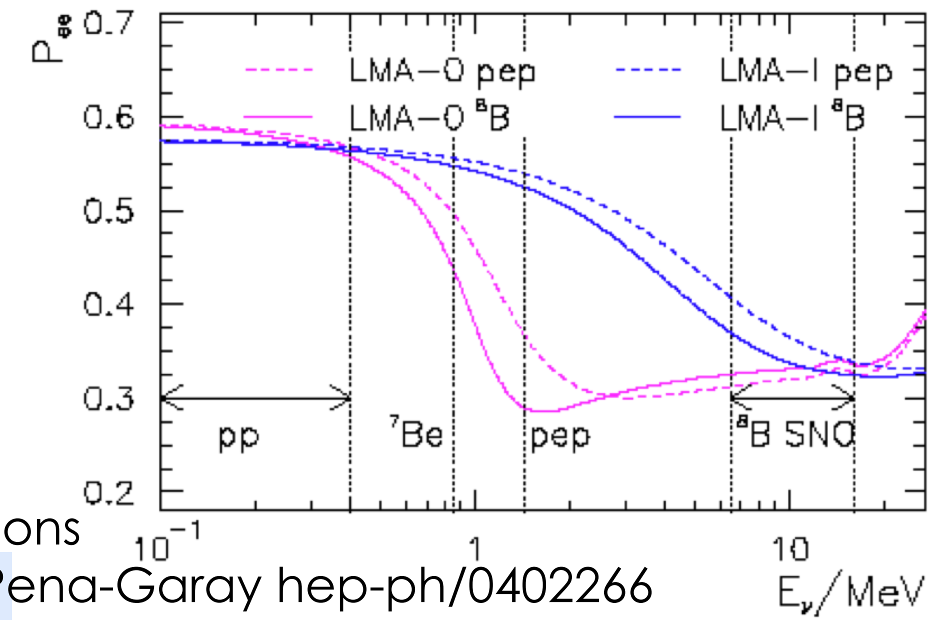


Mass Varying neutrinos
Barger, Huber, Marfatia, hep-ph/0502196



Δm^2_{12} and θ_{12} suggest MSW but direct evidence would be nice

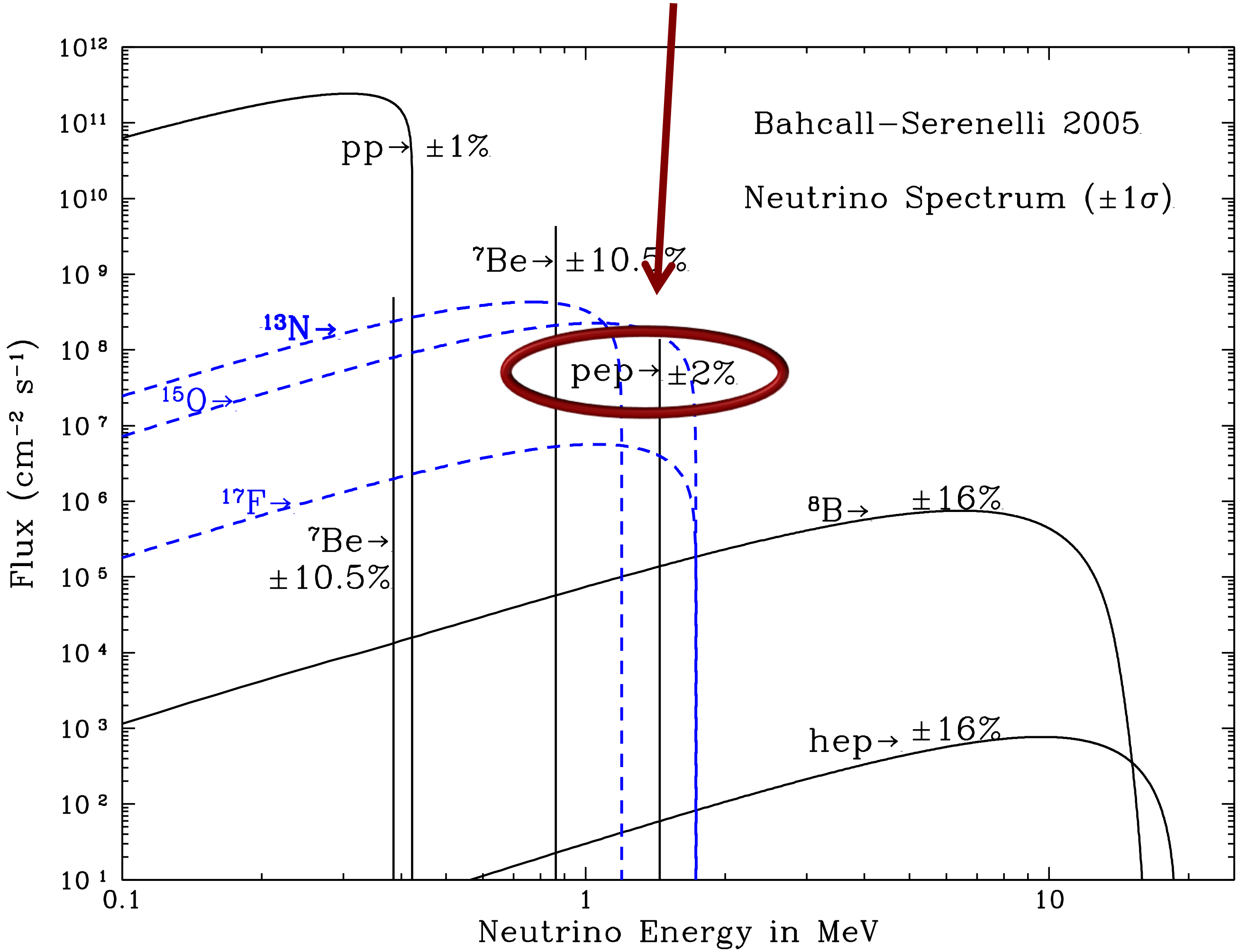
- Day-Night asymmetry
- Spectral distortion of ^8B vs



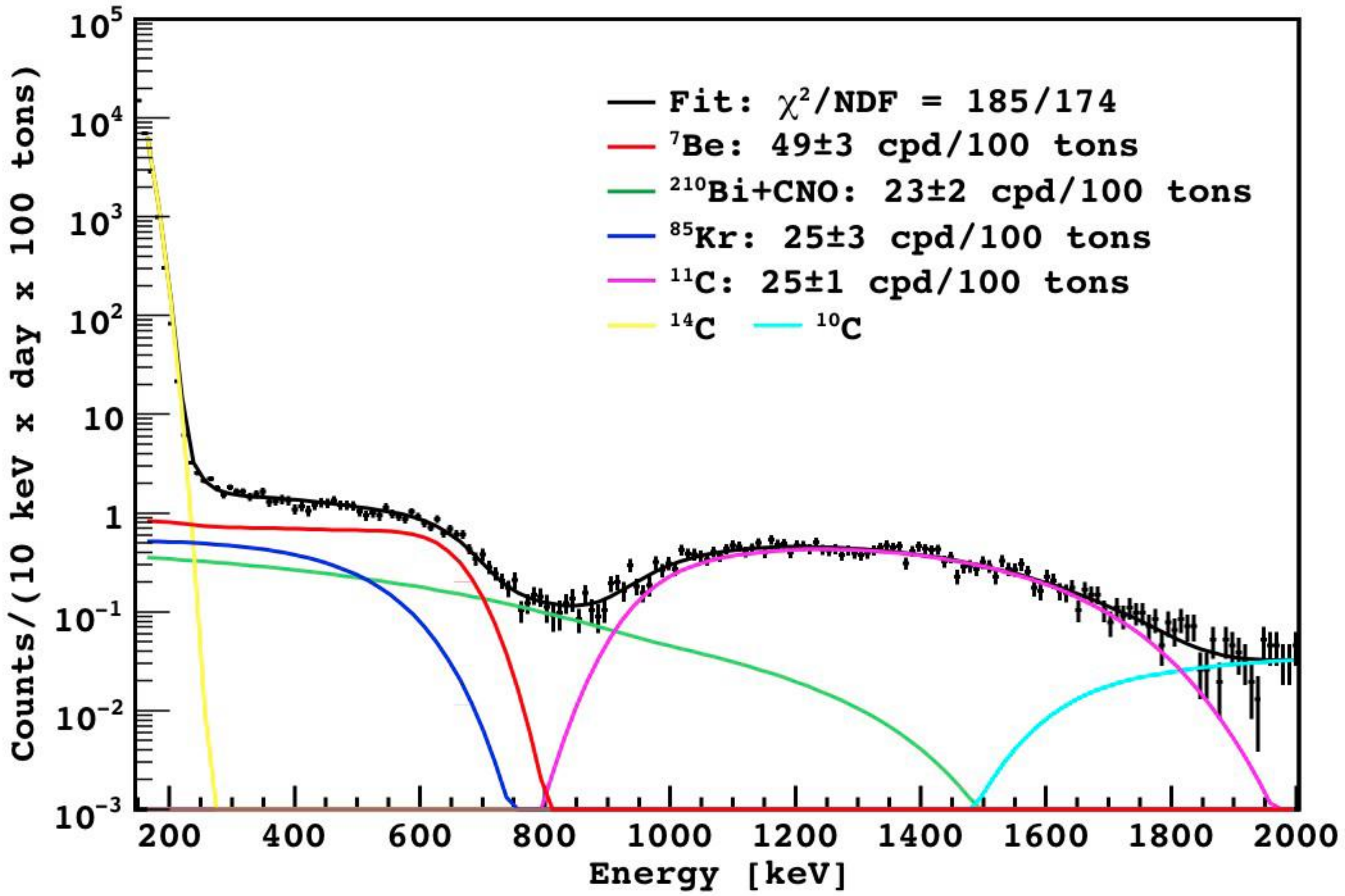
Non- standard interactions
Friedland, Lunardini & Pena-Garay hep-ph/0402266

Solar Neutrinos

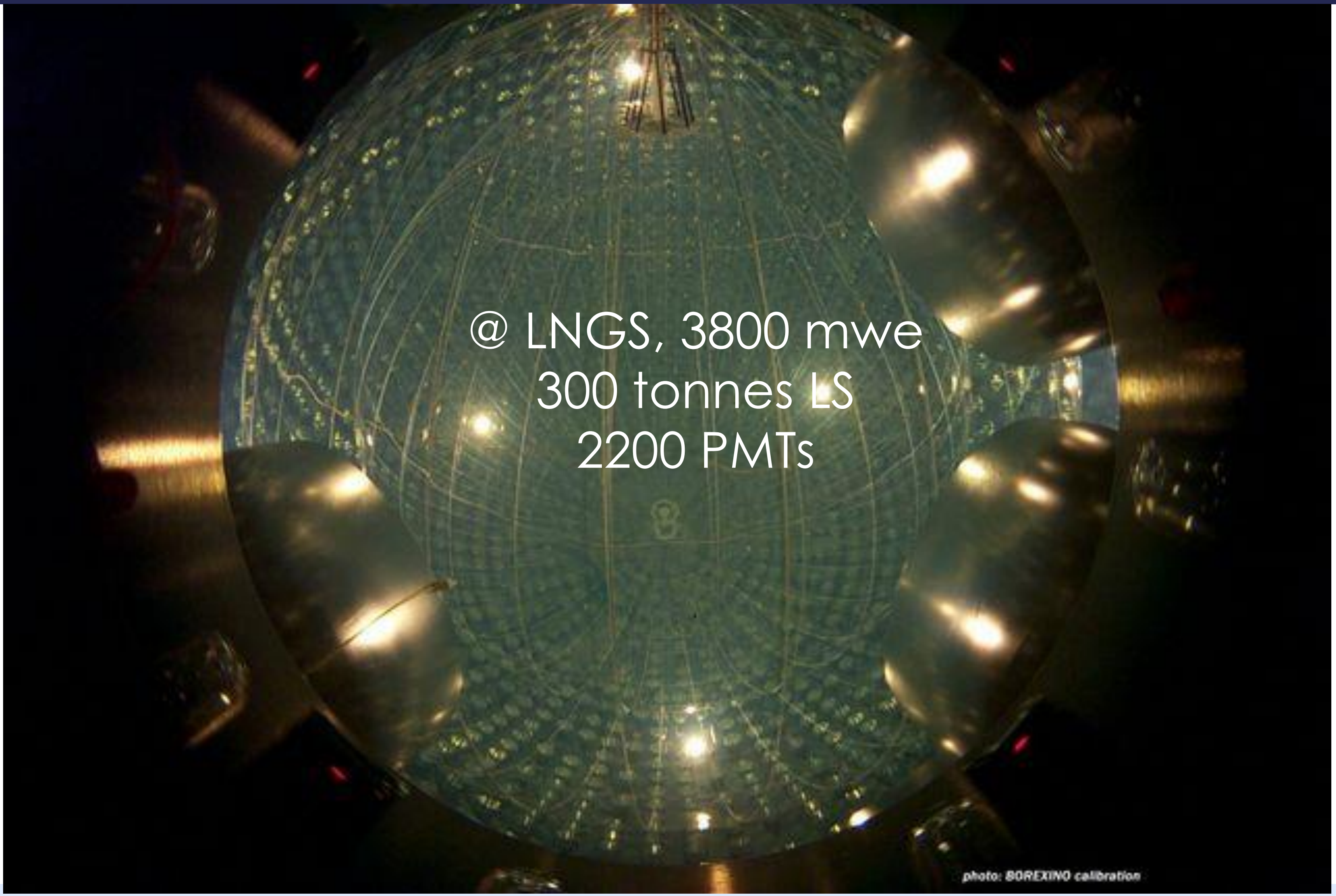
$p + e^- + p \rightarrow {}^2H + \nu_e$



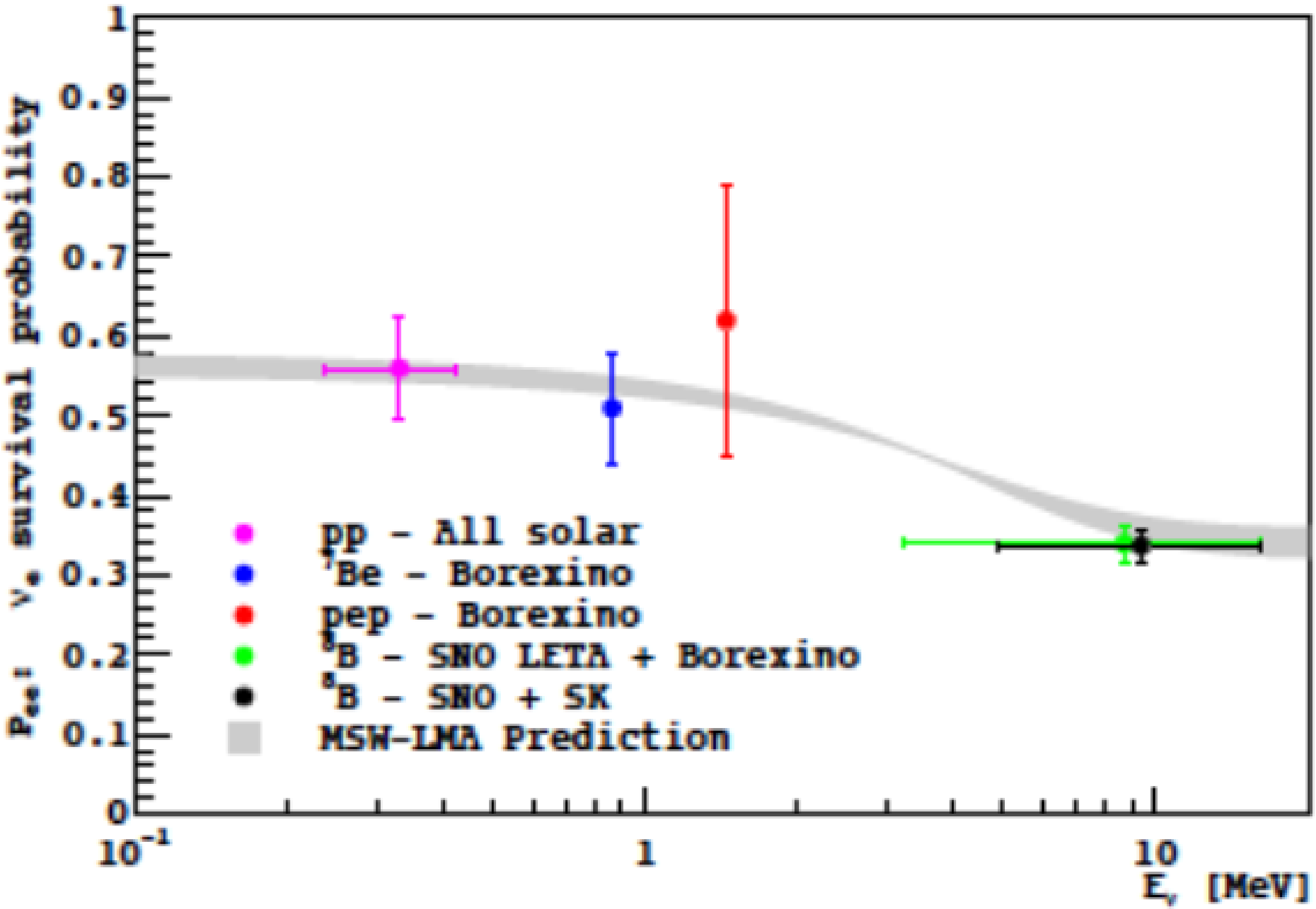
A question of depth: ^{11}C



Borexino

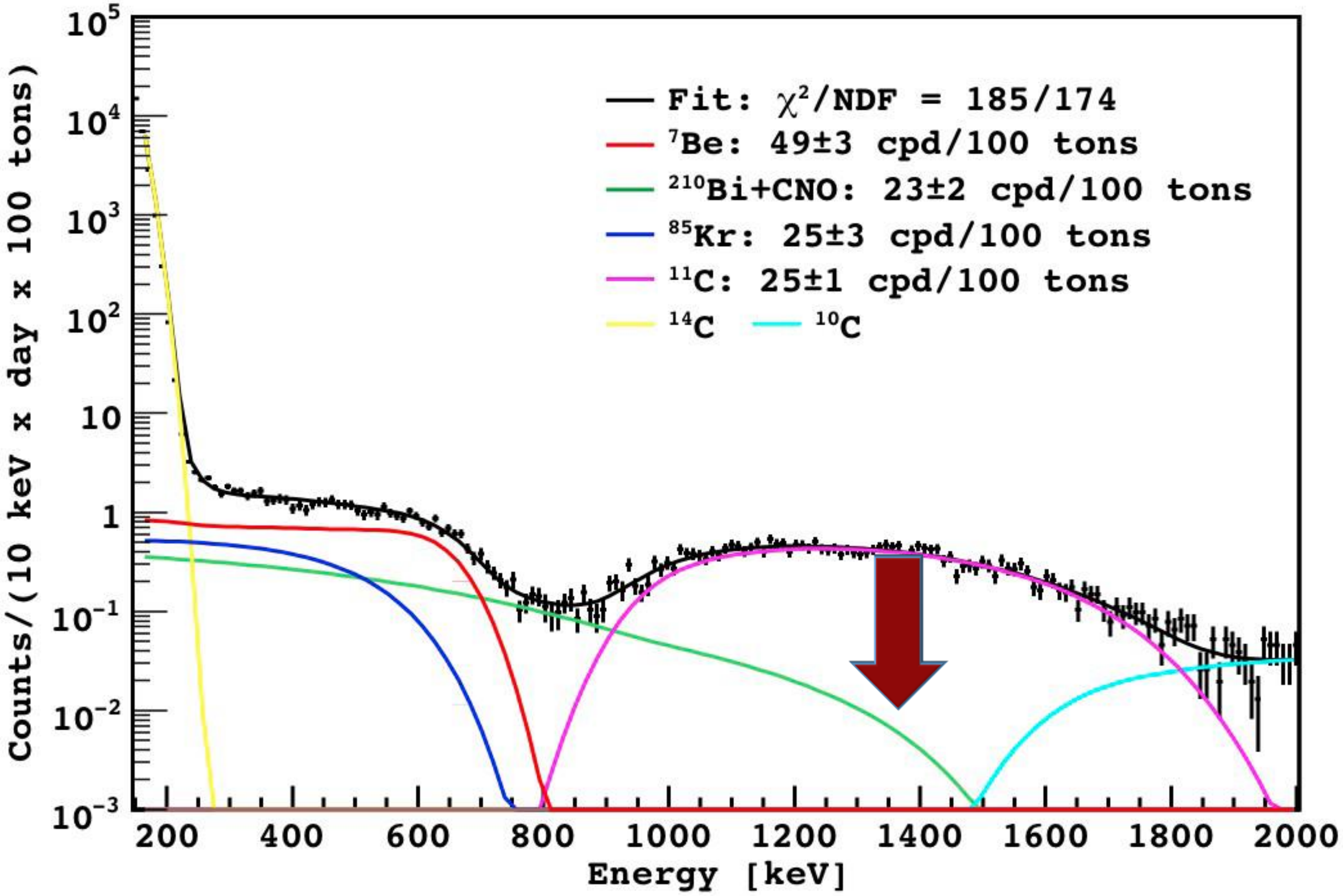

@ LNGS, 3800 mwe
300 tonnes LS
2200 PMTs
photo: BOREXINO calibration

Is LMA the full story?



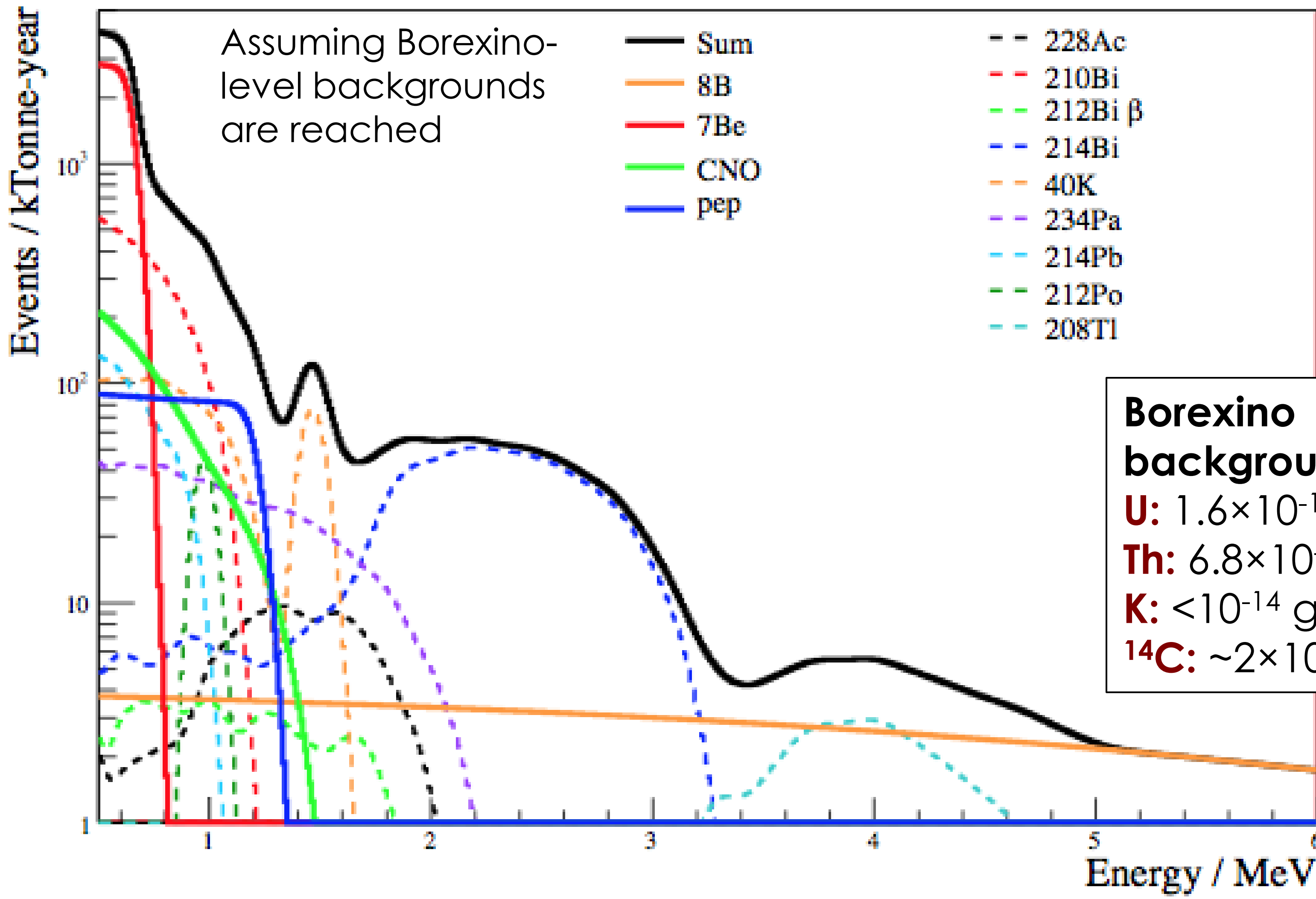
Phys. Rev. Lett. Volume 108, Issue 5, 051302 (2012) **arXiv:1110.3230**

A question of depth: ^{11}C



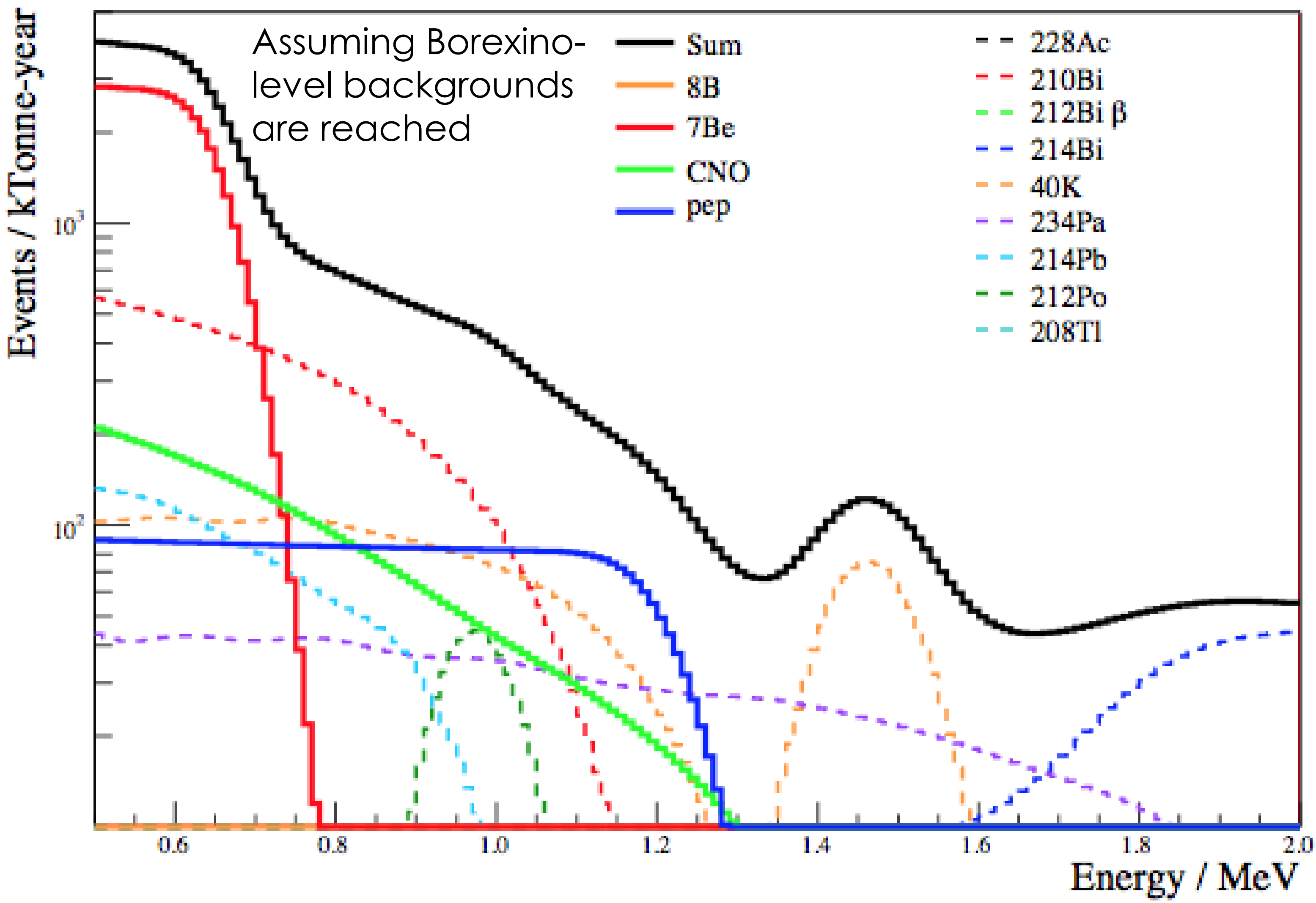
SNO+ Solar signals

^{8}B sensitivity
1 year = 7.5%
2 years = 5.4%



Borexino backgrounds:
U: 1.6×10^{-17} g/g
Th: 6.8×10^{-18} g/g
K: $<10^{-14}$ g/g
^{14}C: $\sim2\times10^{-18}$ g/g

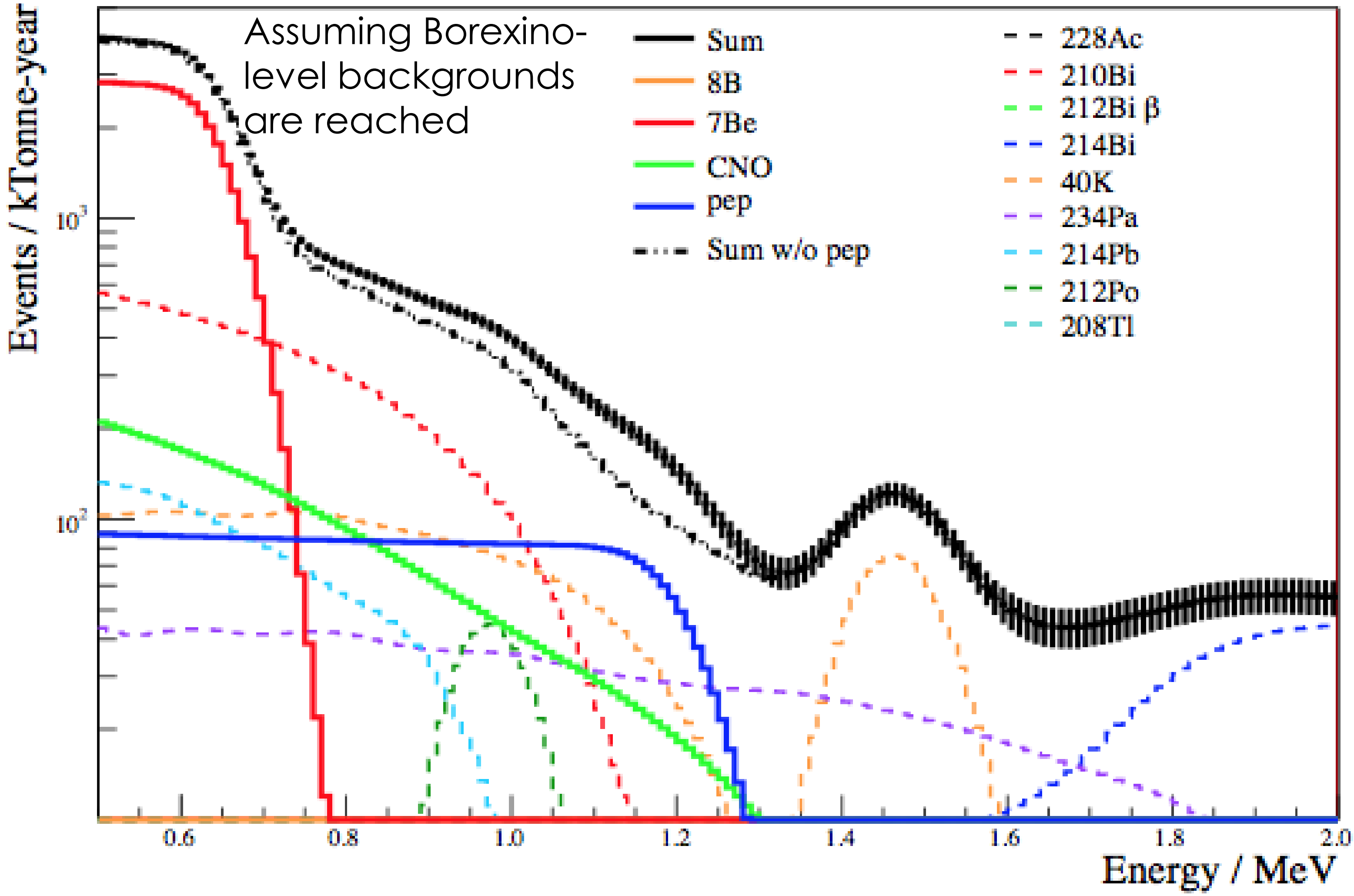
SNO+ solar signals: low E



SNO+ solar signals

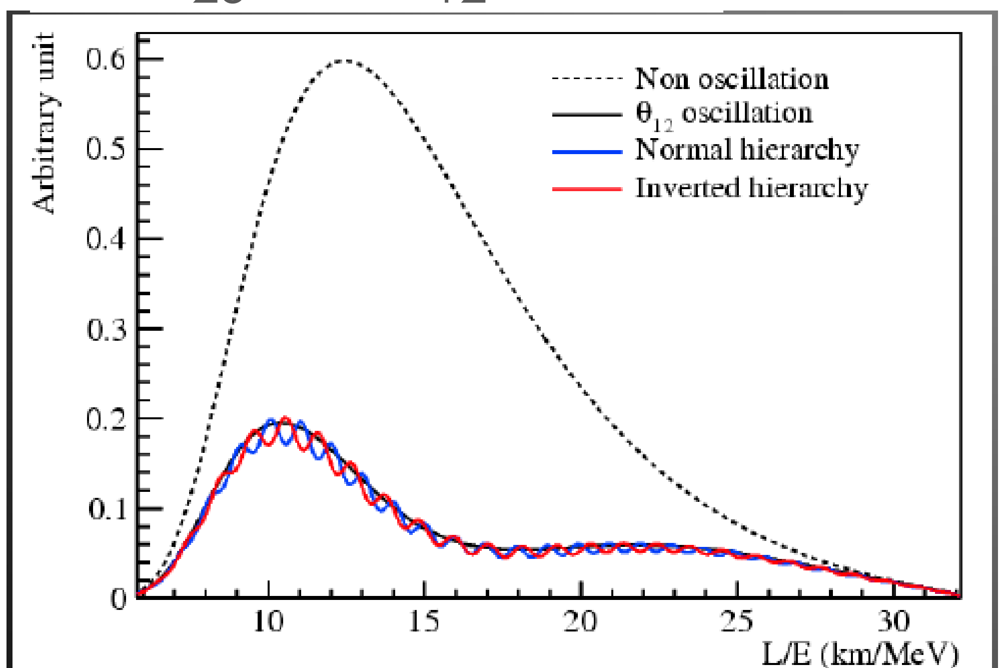
Pep sensitivity
1 year = 9.1%
2 years = 6.5%

1 year data, 50% FV



Neutrino Mass Heirarchy

- Daya Bay 2
  - 20kTon LS detector 60km from Daya Bay reactors (on θ_{12} oscillation maximum)
  - Look for effects of Δm_{23} on θ_{12} oscillation
  - Fourier transform



Neutrino Mass Heirarchy

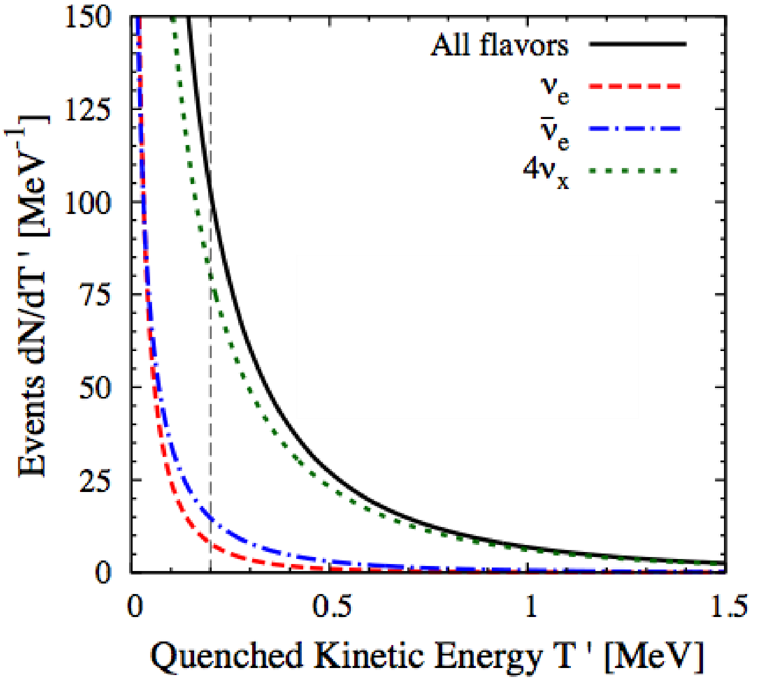
- Daya Bay 2
  - 20kTon LS detector 60km from Daya Bay reactors (on θ_{12} oscillation maximum)
  - Look for effects of Δm_{23} on θ_{12} oscillation
  - Fourier transform analysis
- PINGU
  - Increase detector density in Antarctic Ice cherenkov experiment for sensitivity down to 1GeV atmospheric neutrinos
  - hierarchy sensitivity through neutrino/anti-neutrino asymmetries and matter oscillation effects
- Super-Kamiokande
- Supernovae neutrinos

Neutrino messengers

Ask not what we can learn of the neutrinos, ask what the neutrinos can do for us

SuperNova Neutrino Physics

Supernova Physics



ents in SNO+, SN@10kpc, E>0.2MeV

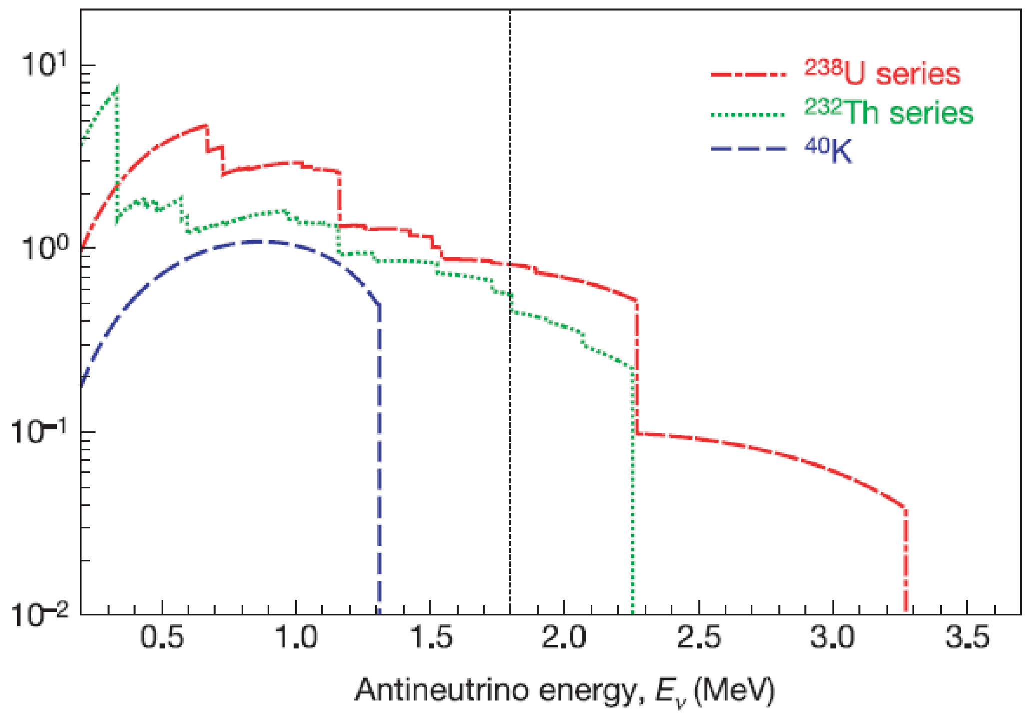
(Anti)Neutrino Interaction	Expected Number of Events
$\nu_e + e^- \rightarrow \nu_e + e^-$	8
$\bar{\nu}_e + e^- \rightarrow \bar{\nu}_e + e^-$	3
$\nu_{\mu,\tau} + e^- \rightarrow \nu_{\mu,\tau} + e^-$	4
$\bar{\nu}_{\mu,\tau} + e^- \rightarrow \bar{\nu}_{\mu,\tau} + e^-$	2
$\bar{\nu}_e + p \rightarrow n + e^+$	263
$\nu_e + {}^{12}C \rightarrow {}^{12}N + e^-$	27
$\bar{\nu}_e + {}^{12}C \rightarrow {}^{12}B + e^+$	7
$\nu_x + {}^{12}C \rightarrow {}^{12}C^*(15.11MeV) + \nu_x$	58
$\nu_x + p \rightarrow \nu_x + p$	273**

- Phys.Rev.D83 arXiv:1103.2768

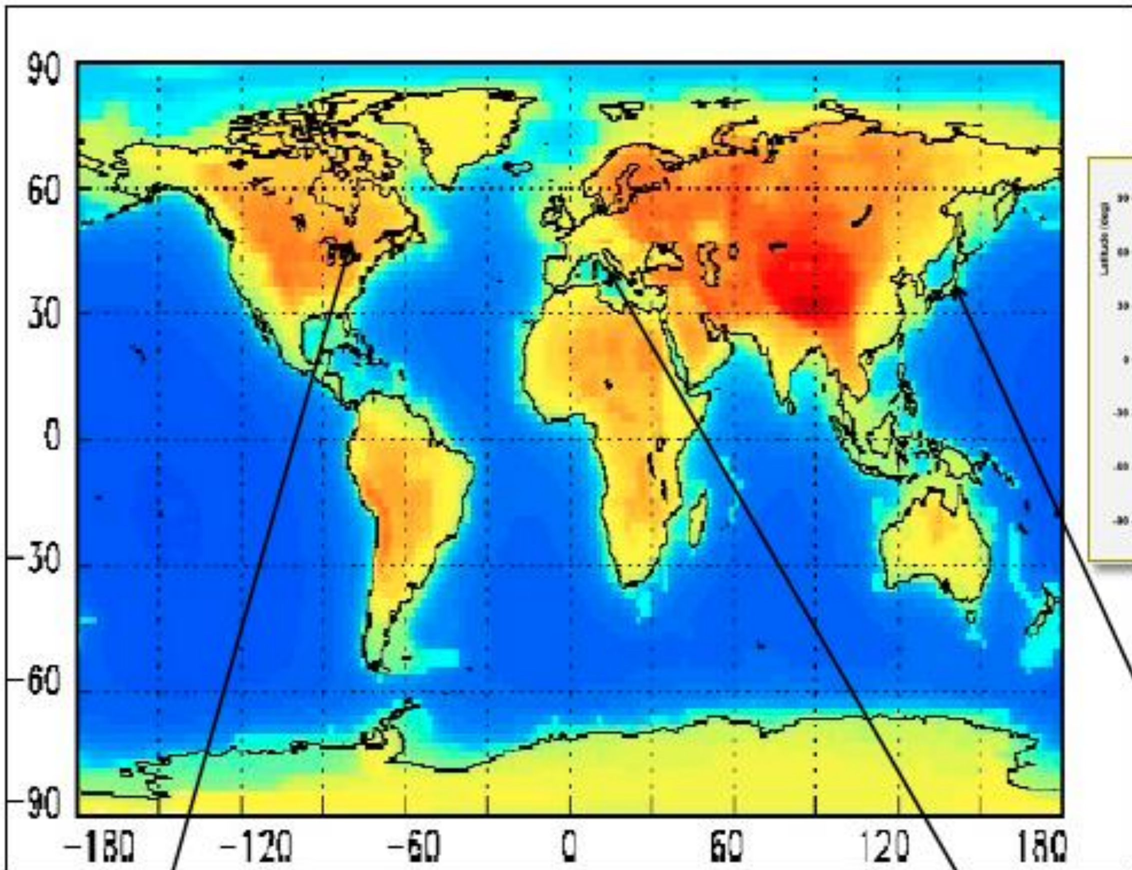
GeoPhysics

Assay the Earth by looking at its neutrino glow

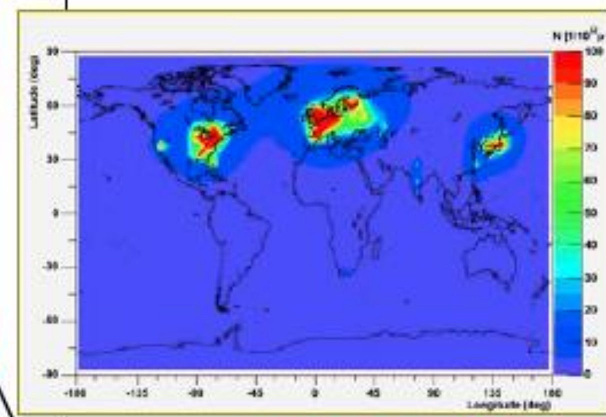
- Radiogenic contribution to heat flow and energetics in the deep earth.
- Test basic models of crust composition



GeoPhysics



from Fiorentini, Mantovani, et al.



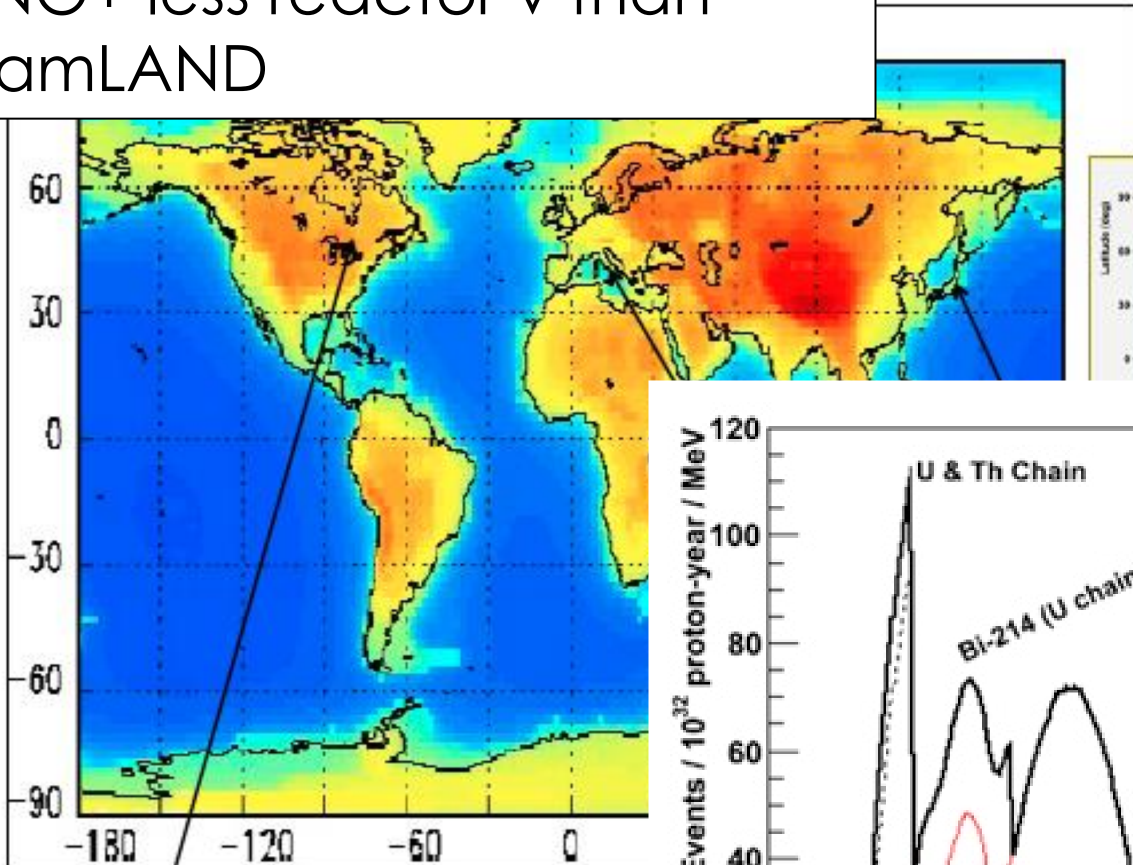
nuclear reactor background

SNO+
near Sudbury, Canada

Borexino
near L'Aquila, Italy

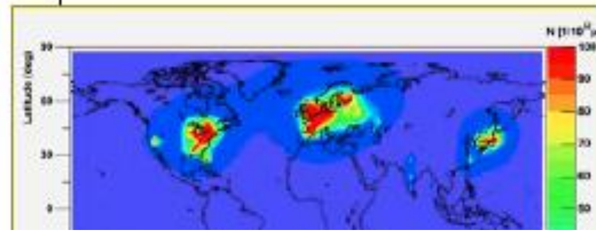
KamLAND
near Kamioka, Japan

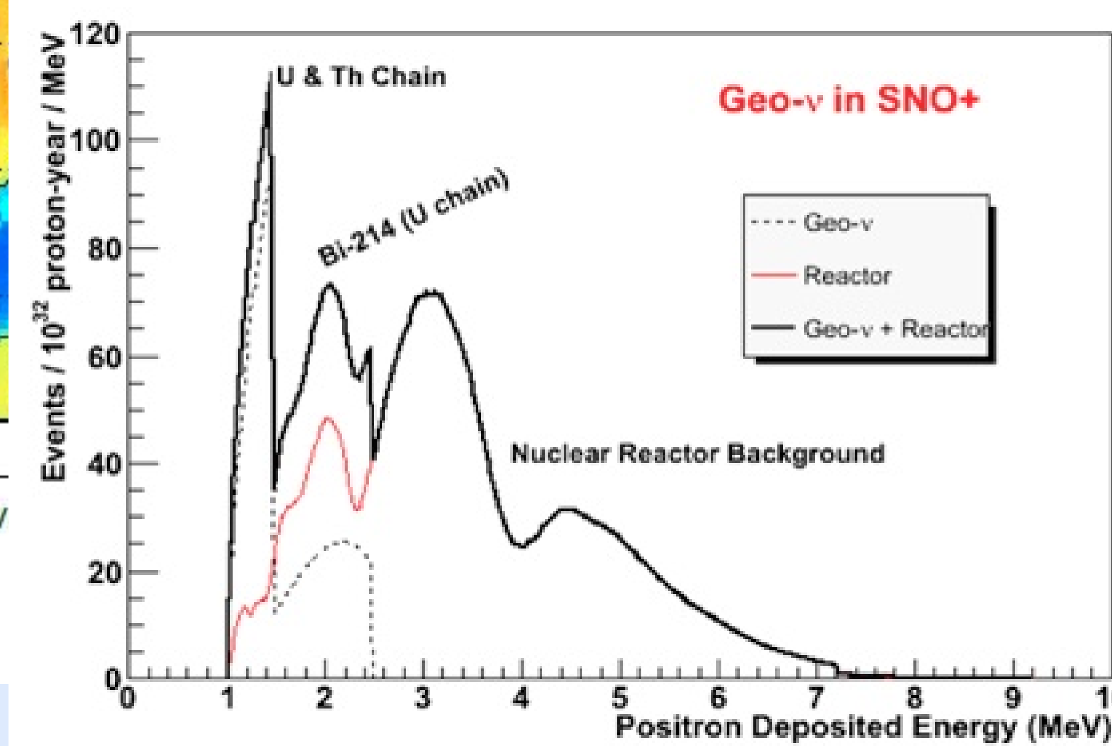
- SNO+ more geoν than KamLAND
    - continental vs oceanic crust
- SNO+ less reactor ν than KamLAND



from Fiorentini, Mantov

SNO+
near Sudbury, Canada



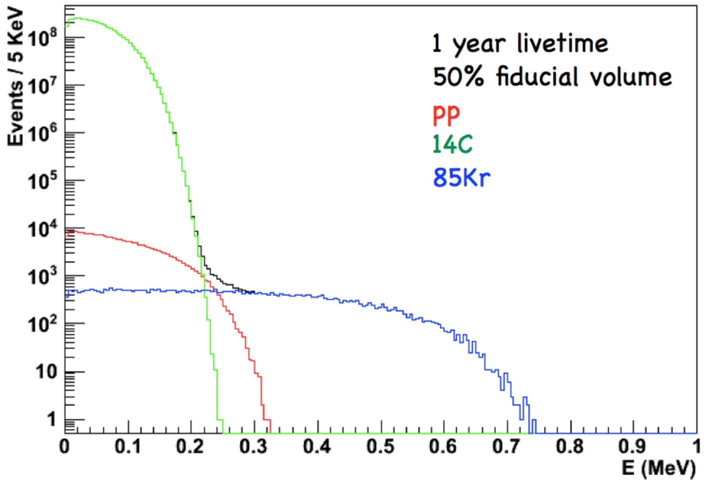


Solar Physics

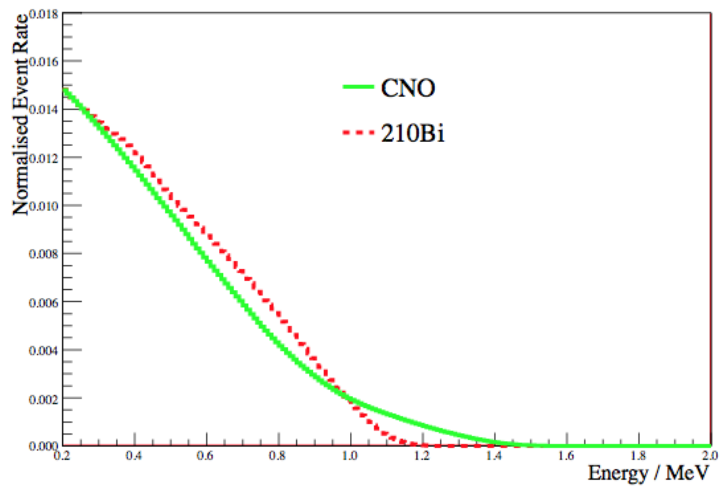
- pp neutrinos:

  $p+p \rightarrow {}^2D + e^+ + \nu_e$

- highest flux, smallest theoretical uncertainty

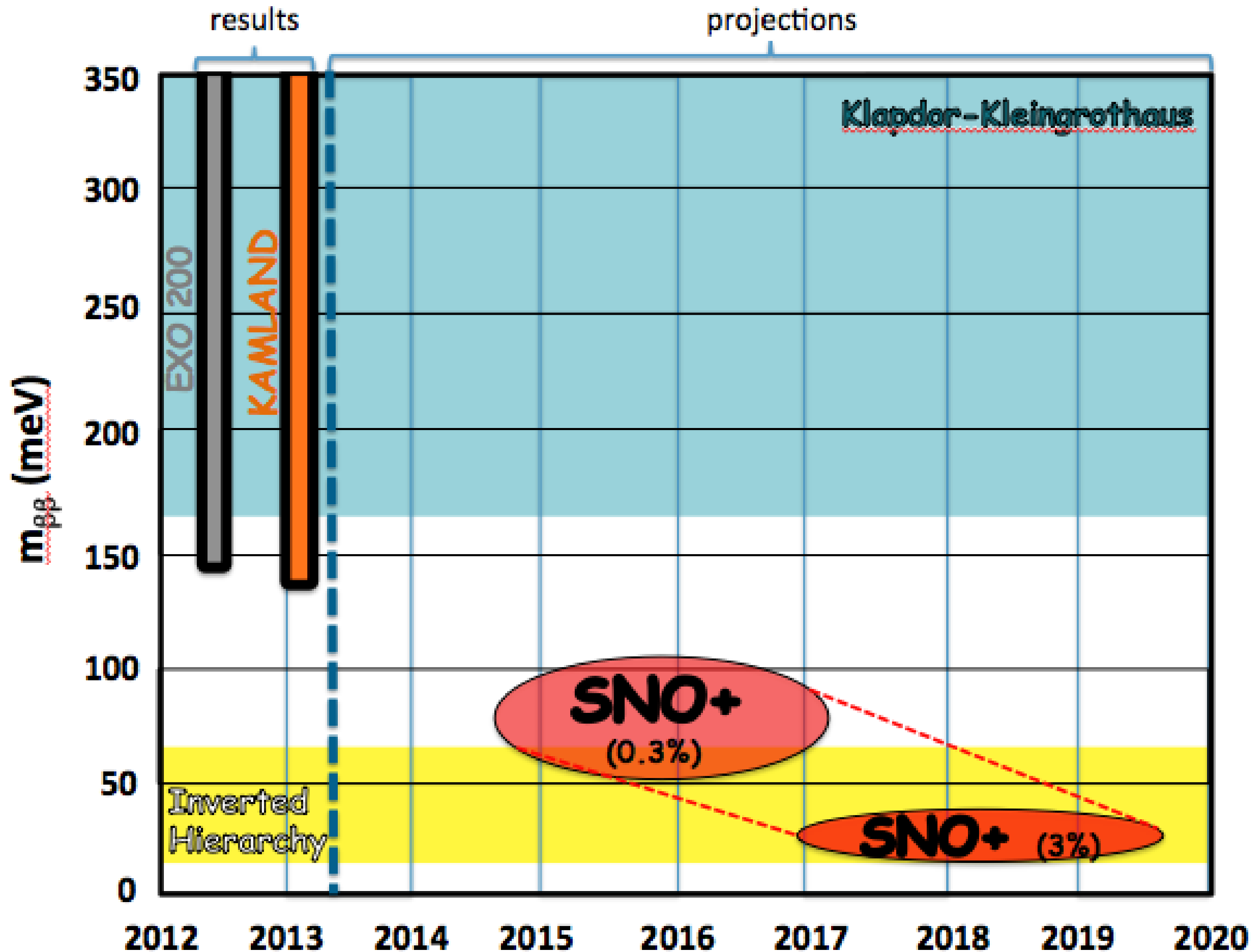


- CNO neutrinos: test solar core metallicity
- Large uncertainty in solar models



DBD Measurements

- As a direct result of work initiated at Oxford, the SNO+ collaboration has identified a more favourable isotope to load into the liquid scintillator for high sensitivity to $0\nu\beta\beta$.
- Following the development of a new metal loading technique and purification method by colleagues at BNL, and a thorough independent internal review of the Oxford/Queens' proposal completed last month (March), the collaboration has decided to pursue the deployment of ^{130}Te as the primary target isotope for double beta decay.
- We are planning for an initial loading corresponding to 800kg of ^{130}Te (0.3%) to begin in 2014. Following a successful demonstration of this phase and pending results from the continuing R&D effort, we would then aim to increase the loading to the multi-tonne scale as soon as is feasible, with the goal of achieving sensitivity near the bottom of the inverted neutrino mass hierarchy.

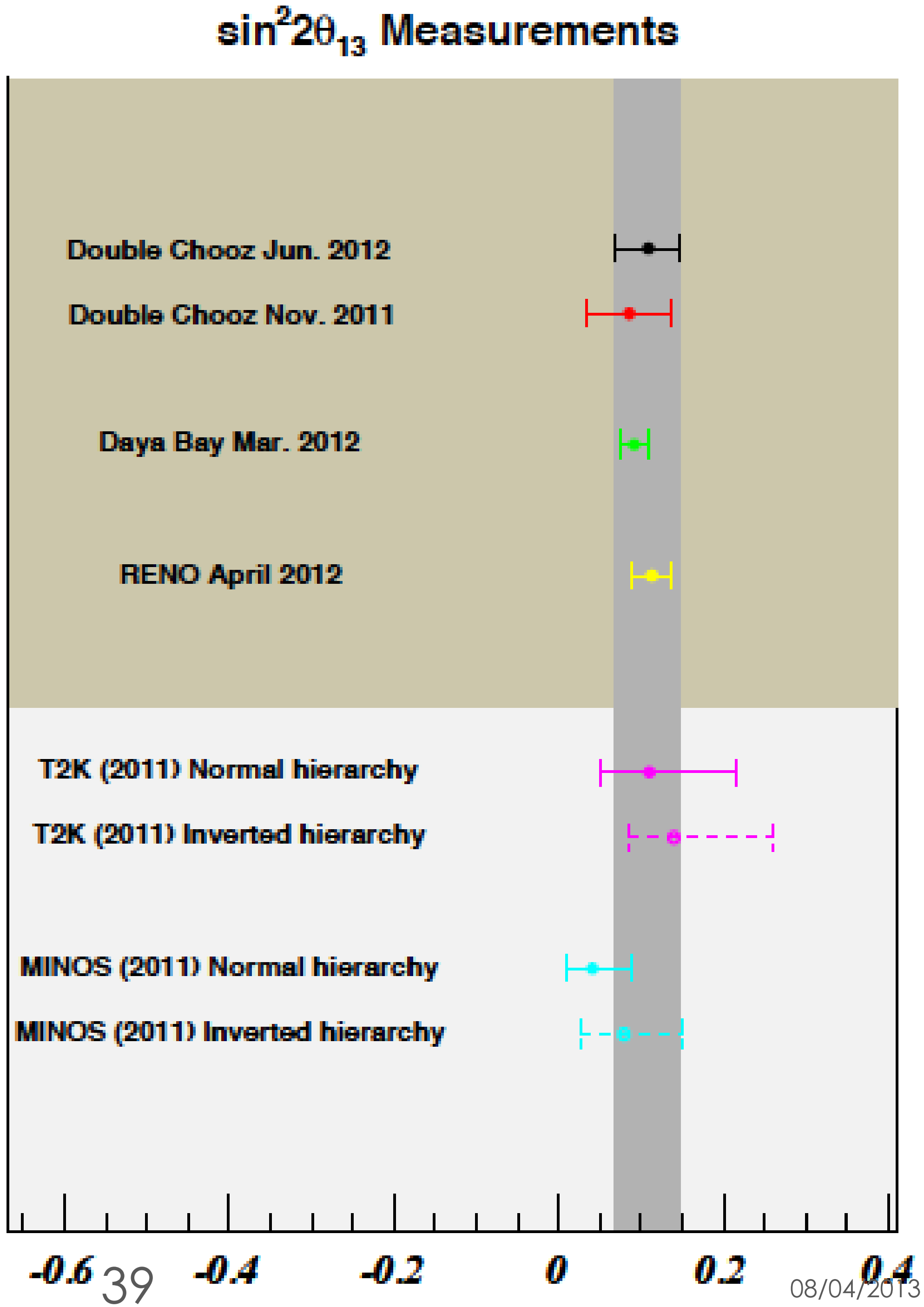

results
projections
Klapdor-Kleingrothaus
EXO 200
KAMLAND
$m_{\beta\beta}$ (meV)
350
300
250
200
150
100
50
0
SNO+
(0.3%)
SNO+ (3%)
Inverted Hierarchy
2012
2013
2014
2015
2016
2017
2018
2019
2020

Summary

- Reactors, Solar, SN neutrinos useful tools to probe neutrino properties
- Neutrinos becoming useful tools to understand neutrino sources
- It's hard – need big, deep, multi-purpose experiments.
- Balancing act against other purposes
  - SNO+ to focus on $0\nu\beta\beta$ with ^{130}Te
- Apologies for everything I missed out:
  - Atmospheric vs, SuperNova relicvs, AGNs, GRBs, …

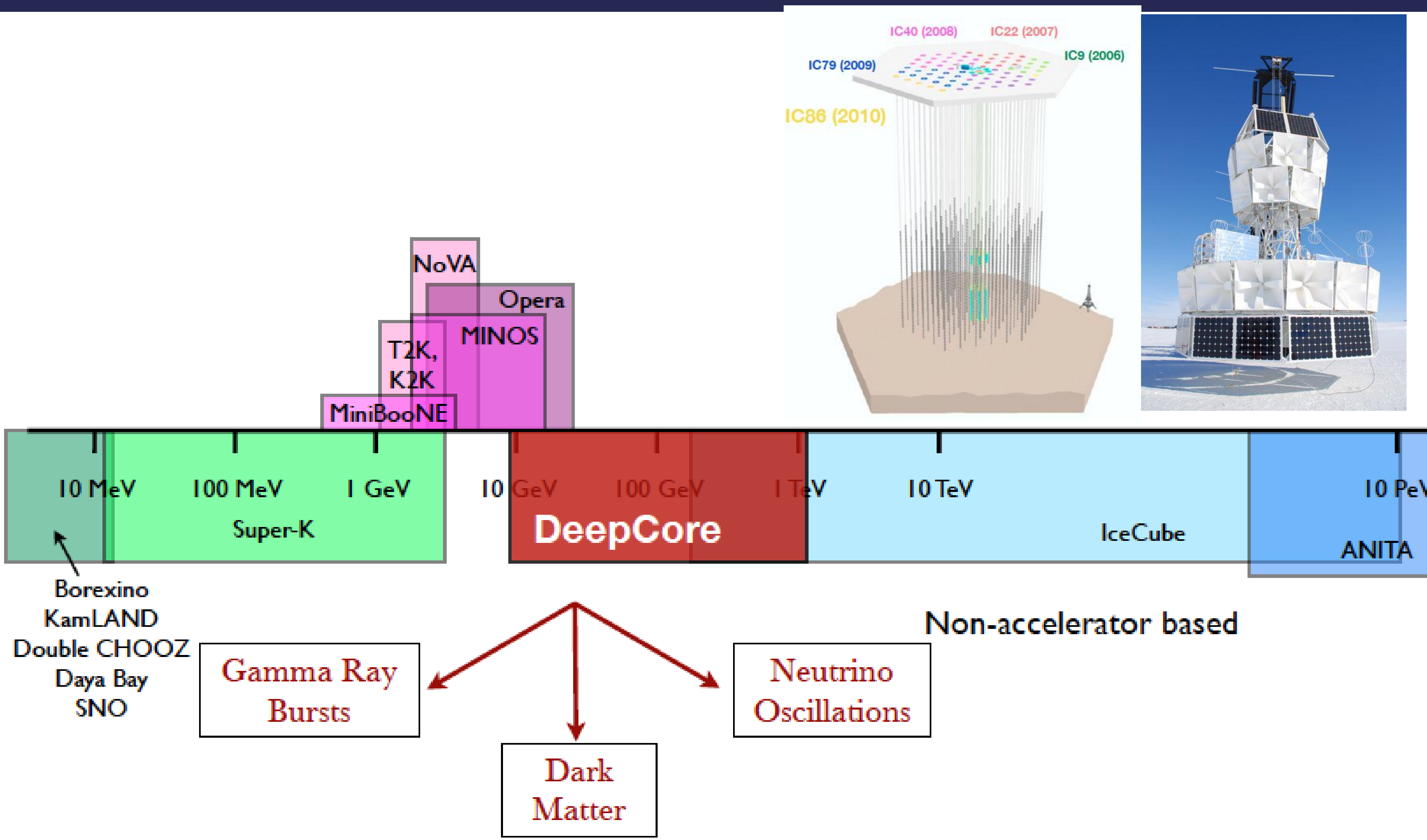
Backup slides

Reactor θ_{13}



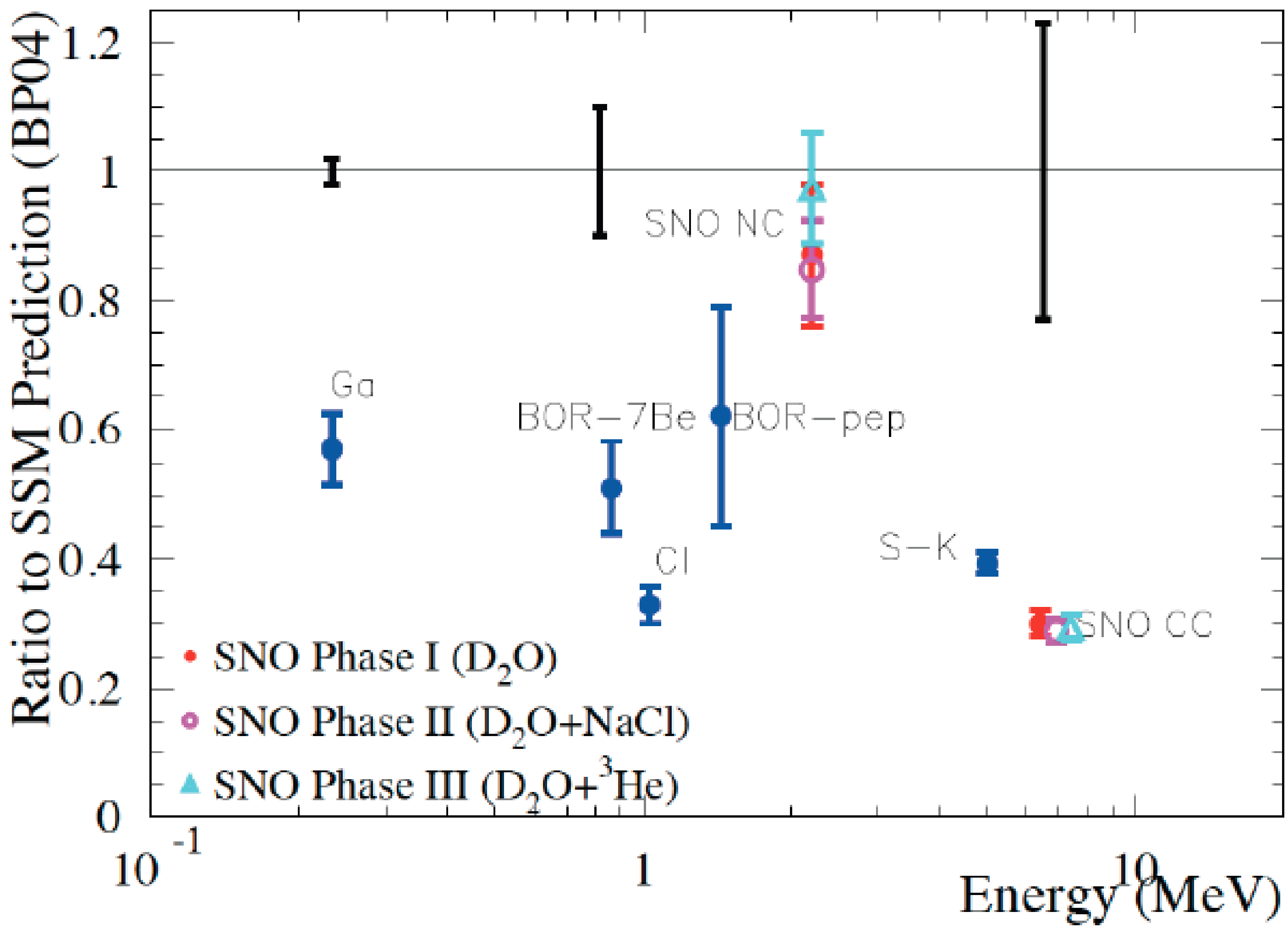
http://arxiv.org/pdf/1207.6632.pdf

Extra-terrestrial neutrinos

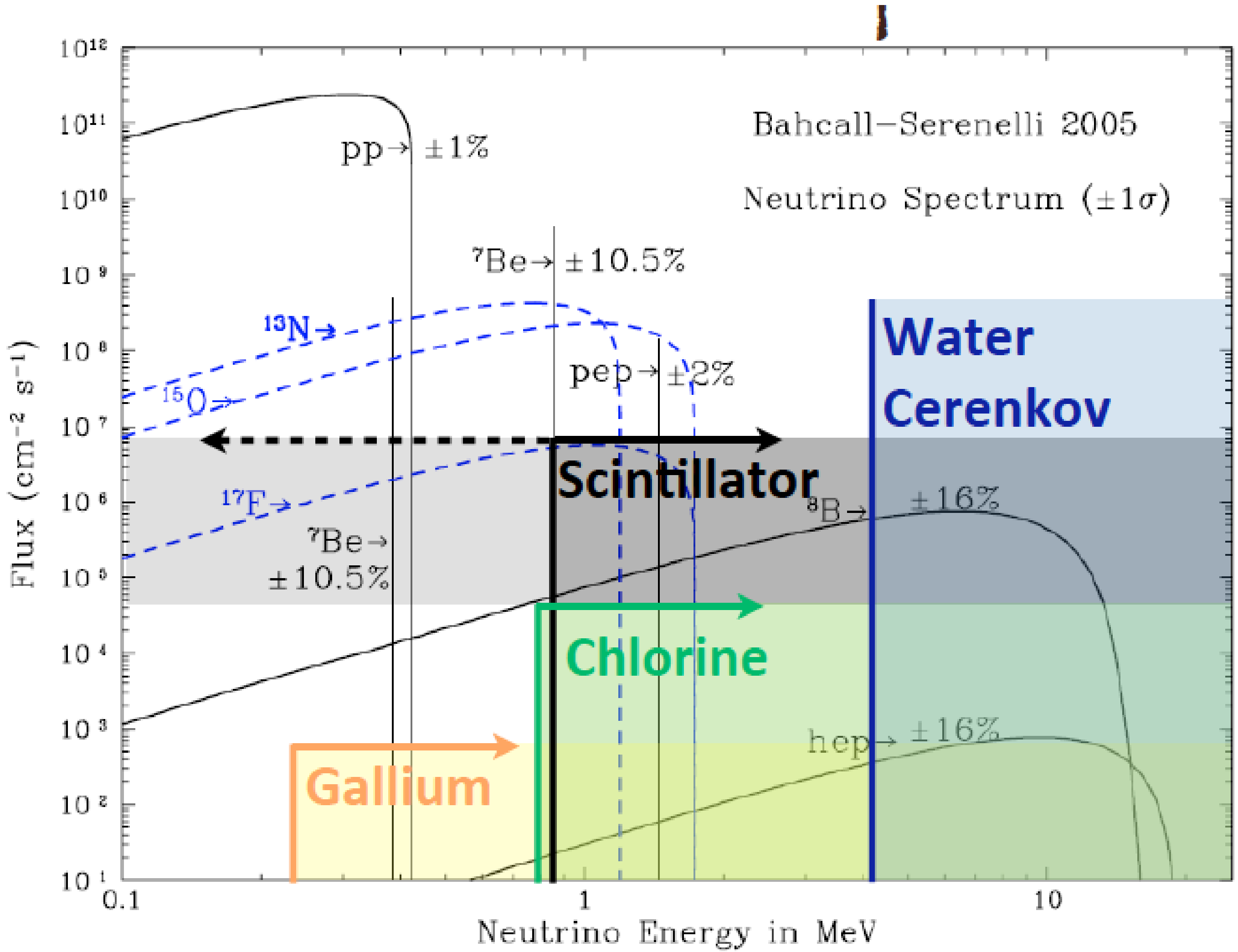


http://alexfriedland.com/info11/info
ks/Koskinen-INFO11.pdf

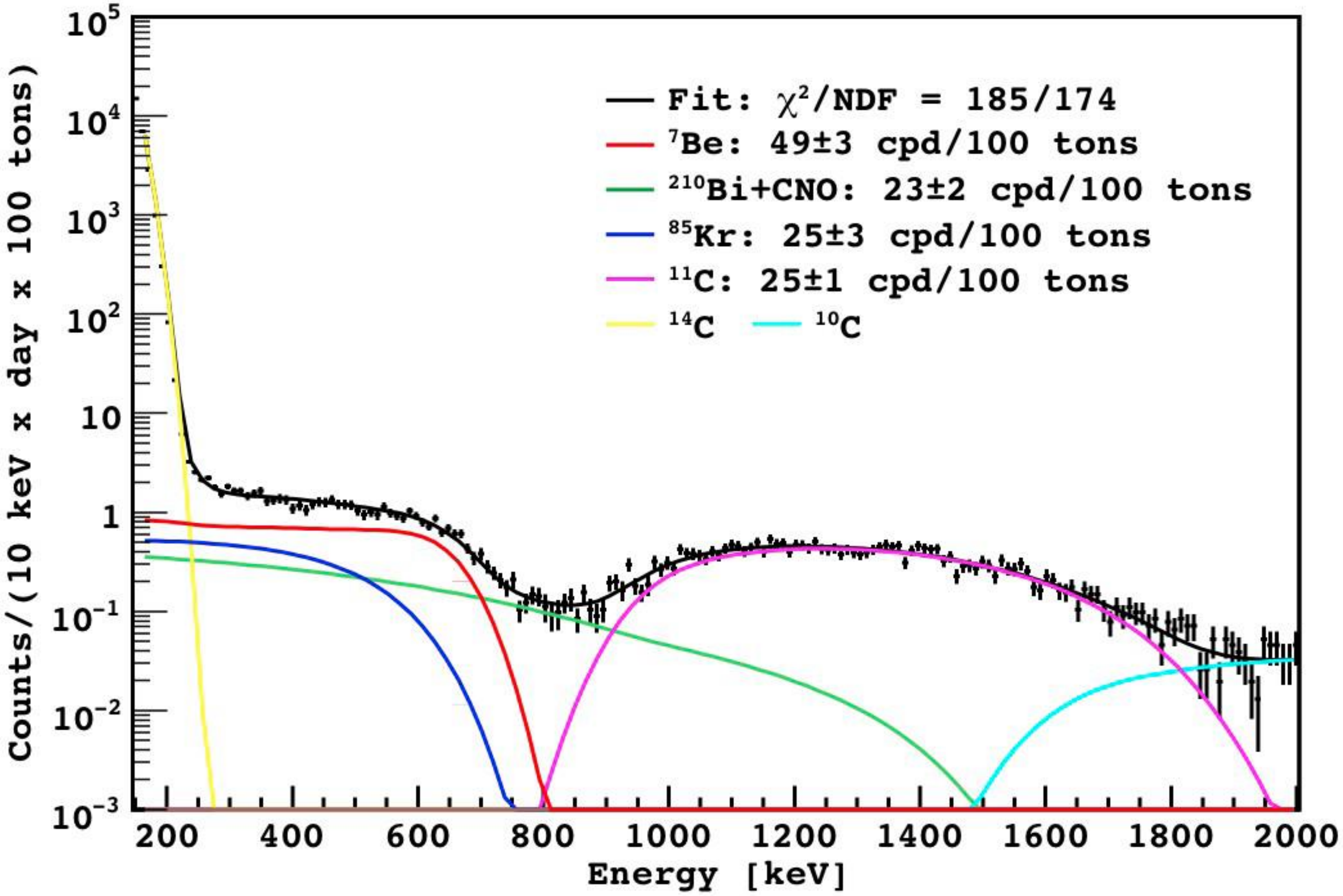
Solar Neutrinos



Solar neutrinos



Other Low E Backgrounds



SNO+ Solar Prospects

SNO+ has decided to prioritise 0νββ

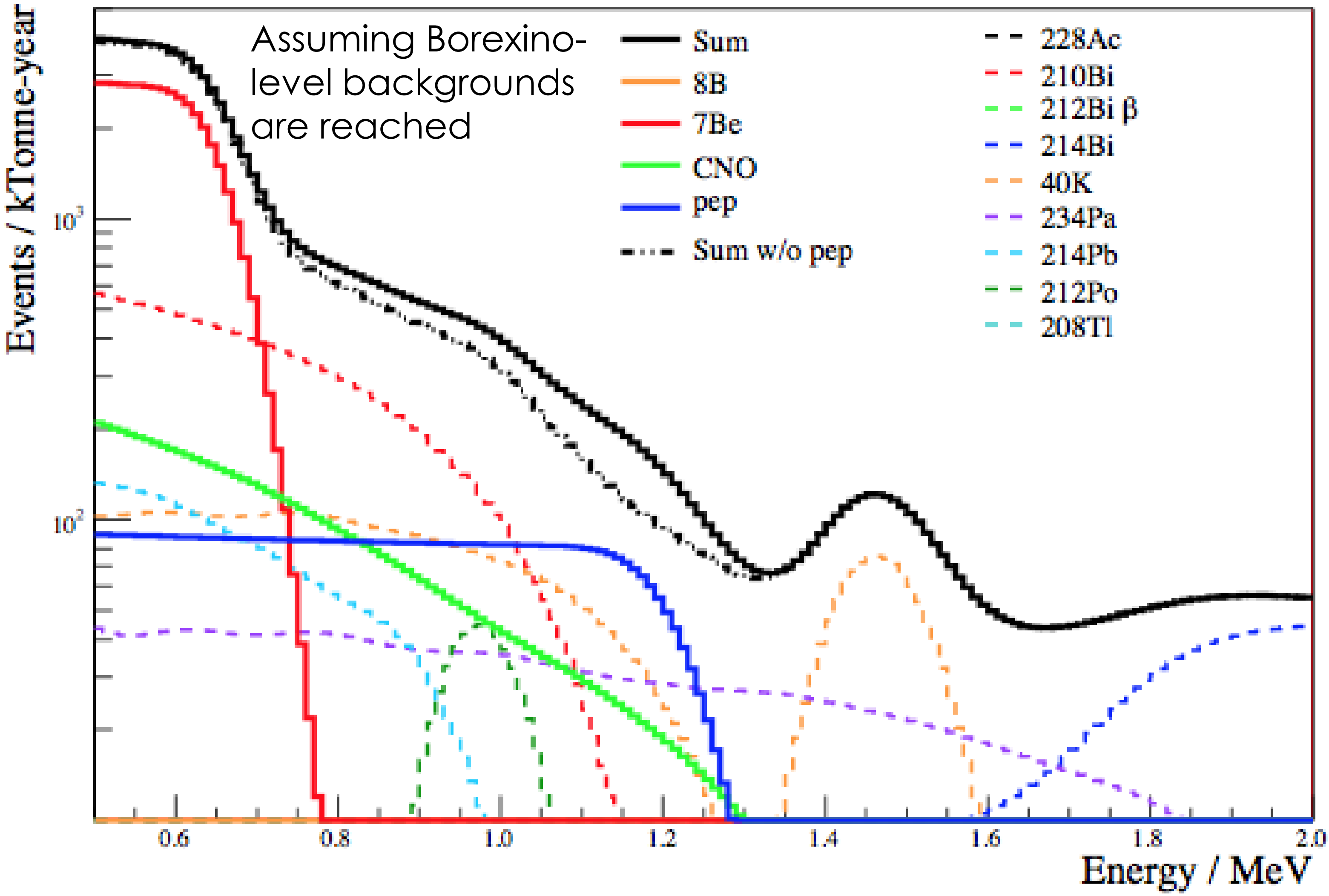
• Radon daughters have accumulated on the surface of the AV over the last few years in a significant way. If these leach into the scintillator, the purification system has the capability to remove them.

• However, depending on the actual leach rate, that removal might be inefficient and the ^{210}Bi levels in the scintillator too high for a pep/CNO solar neutrino measurement without further mitigation.

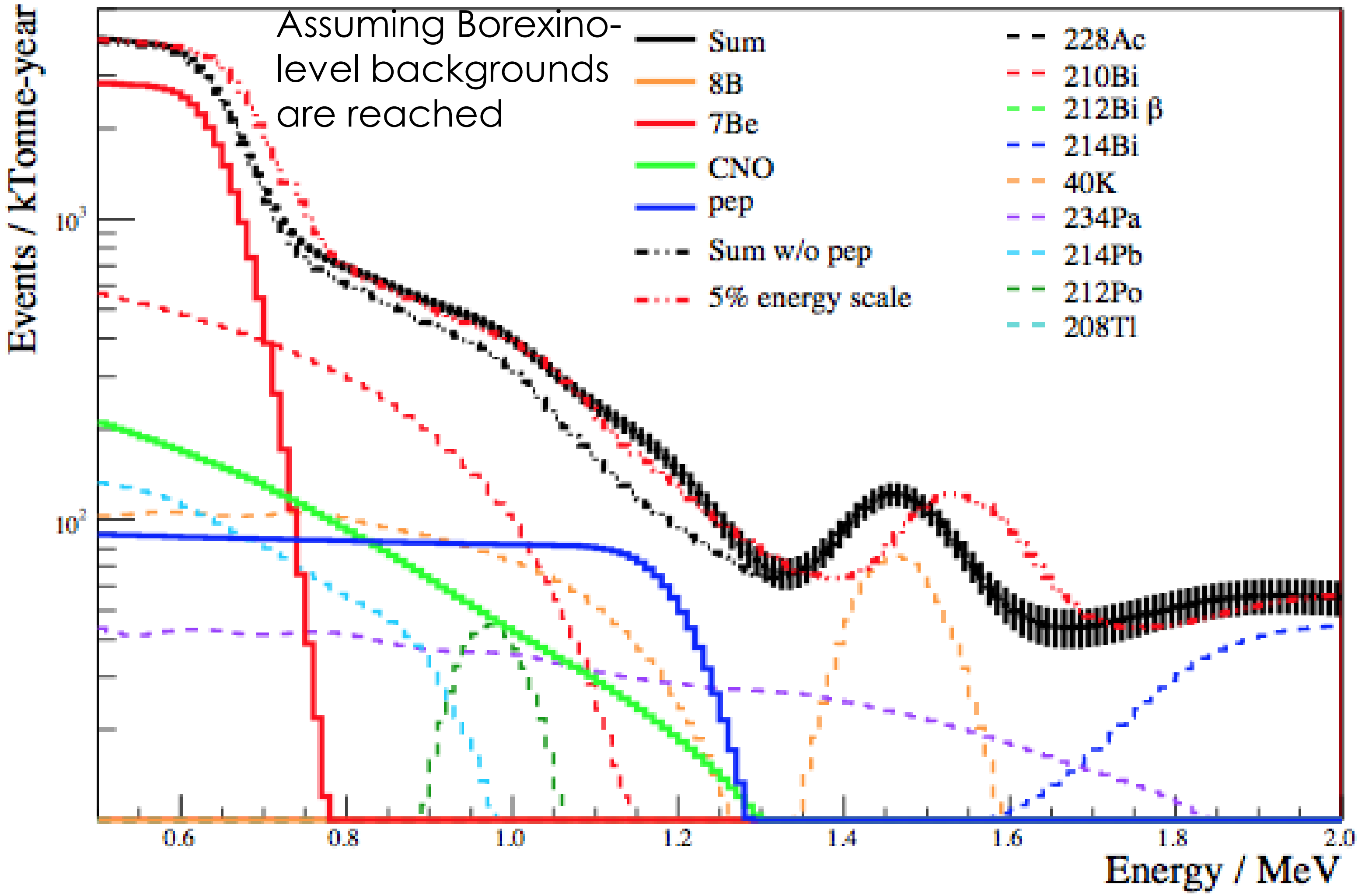
• Mitigation could include enhancing online scintillator purification, draining the detector and sanding the AV surface to remove radon daughters, or deploying a bag.

• 0νββ and low-energy 8B solar neutrino measurements are not affected by these backgrounds

SNO+ solar signals

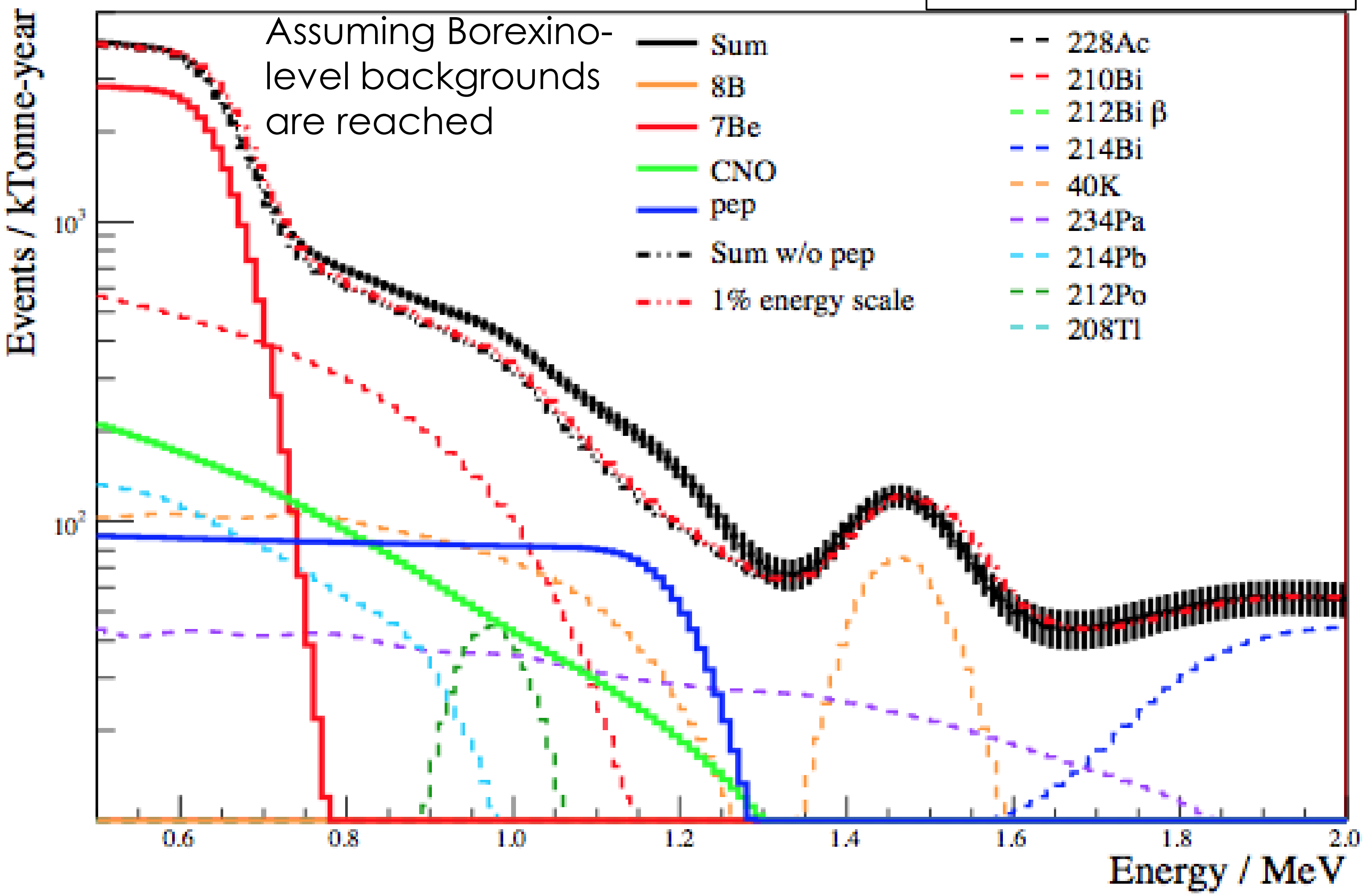


SNO+ solar signals

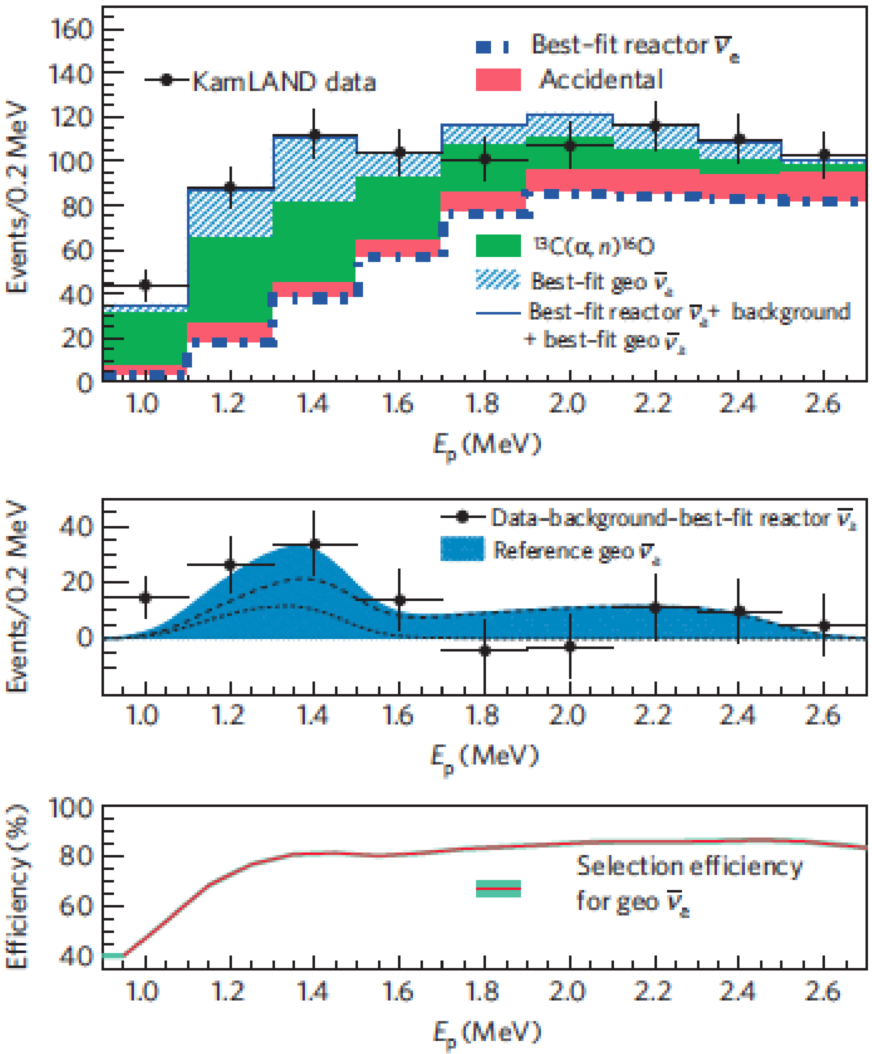


SNO+ solar signals

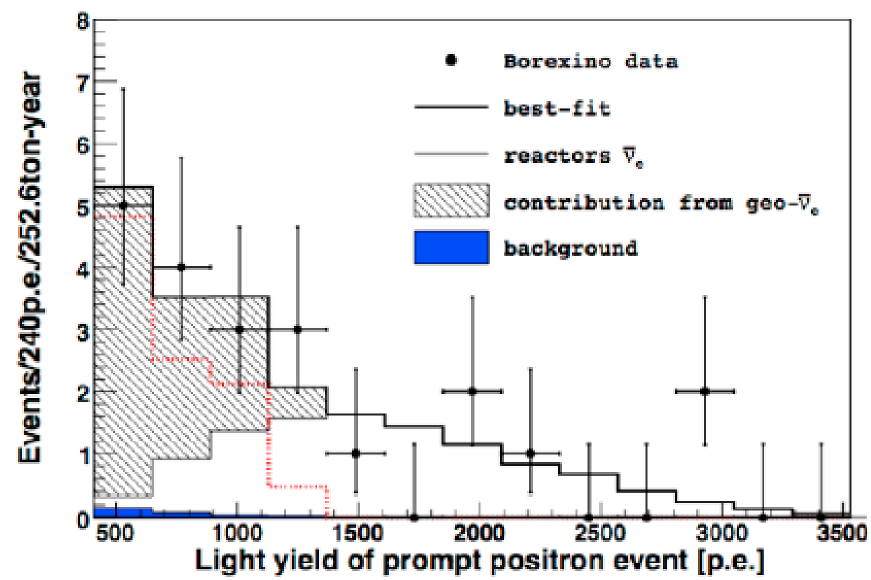
Pep sensitivity
1 year = 9.1%
2 years = 6.5%



GeoPhysics



- KamLAND and Borexino combined:
- 20 ±9 TW from U & Th

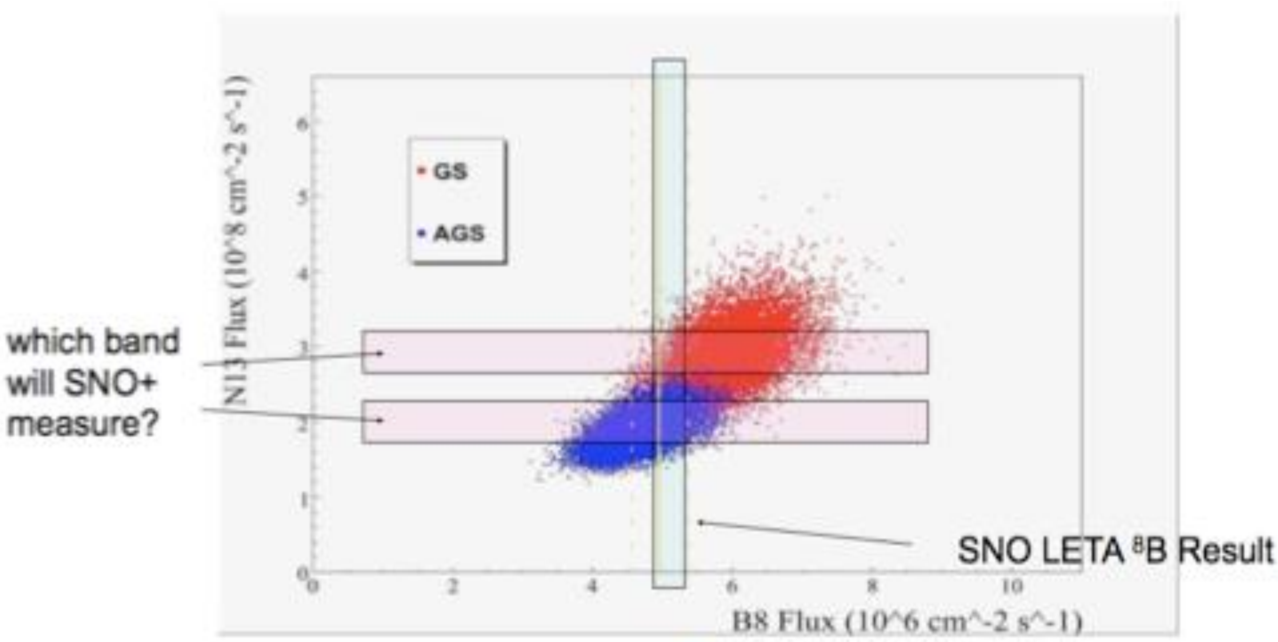


SuperNova Neutrino Physics

- Challenge to decouple details of SN model from neutrino physics.
- model ~independent handles on mass hierarchy (θ_{13} large):
  - Modulations in νspectra by day-night effect -> IH
    arXiv: hep-ph 0412100, 0304150
  - Fast O(100ms) rise-time of $\bar{\nu}_e$ lightcurve prefers IH
    arXiv:1111.4483

Solar Physics – core metallicity

- Tension helioseismology ←→ photosphere spectroscopy
- Use SNO 8B to constrain environmental variables (core T)
- Measure CNO flux and compare to solar models to differentiate high and low metallicity



A la Haxton and Serenelli arXiv:0902.0036

Solar Physics – CNO neutrinos

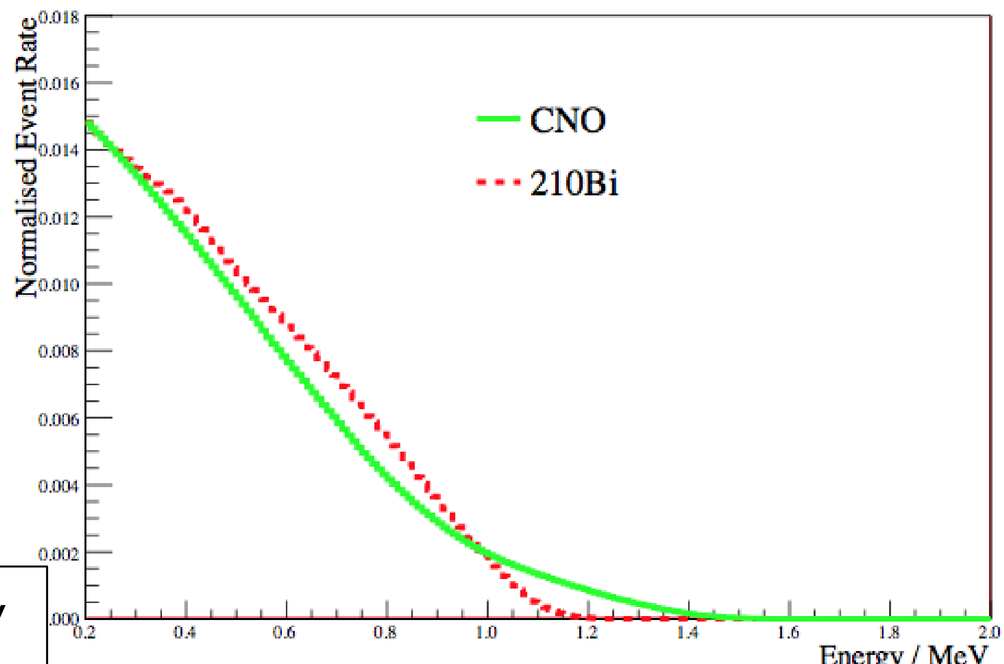
$^{210}Bi \longrightarrow ^{210}Po \longrightarrow ^{206}Pb$

β, $T_{½}$ ≈5days

5.3MeV a, $T_{½}$ ≈138days

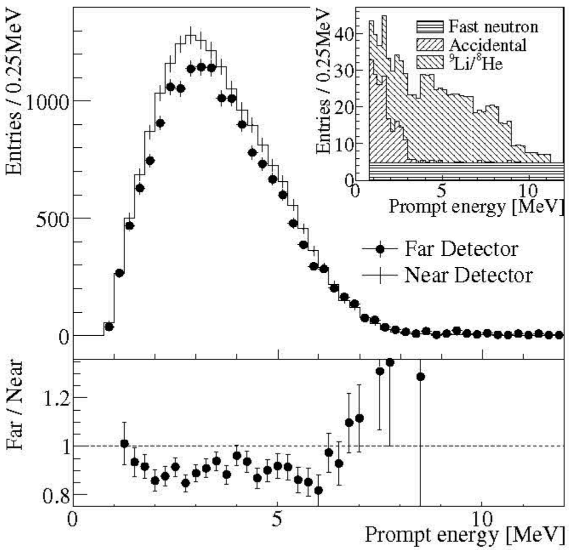
Examine time evolution of ^{210}Po a rate

http://arxiv.org/abs/1104.1335

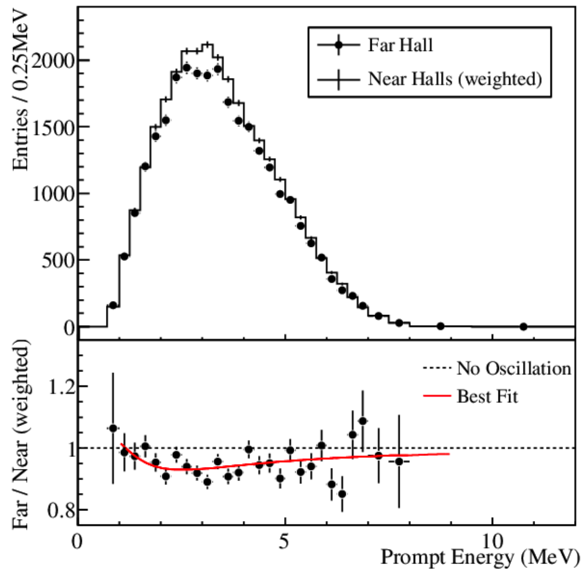


CNO sensitivity ~15%

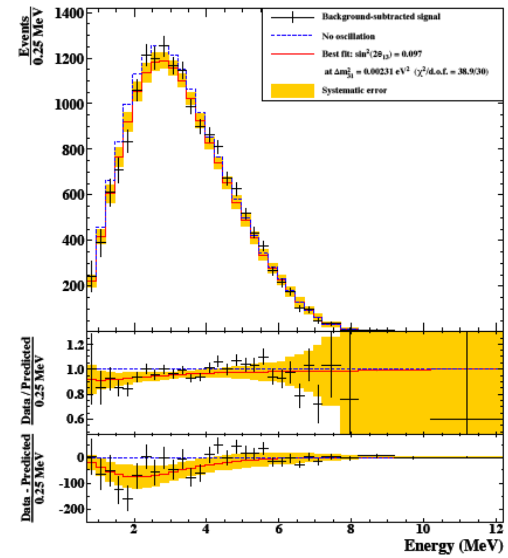
Daya Bay, RENO, Double Chooz



RENO



Daya Bay



Double Chooz

Experiment	$\sin^2 2\theta_{13}$	*stat.*	*syst.*
RENO	0.113	± 0.013	± 0.019
Daya Bay	0.089	± 0.010	± 0.005
Dbl Chooz H	0.097	± 0.034	± 0.034
Dbl Chooz Gd	0.109	± 0.030	± 0.025

Rate only (RENO, Daya Bay)

Rate + Shape (Dbl Chooz H, Dbl Chooz Gd)